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A study of of asymmetrical simultaneous 2-hand reach motions in the horizontal plane.

Manchow Mak
University of Windsor

A Study of

Asymmetrical Simultaneous 2-hand Reach Motions

in the Horizontal Plane

by

MANCHOW MAK

A Thesis

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To my family

ABSTRACT

A Study of Asymmetrical Simultaneous 2-hand Reach Motions in the Horizontal Plane

Fourteen subjects, seven right-handed and seven left-handed, performed both asymmetrical simultaneous 2-hand reach motions and single-handed reach motions. Four levels of distance traveled for both right hand and left hand (3", 6", 9", 12"), two levels of angles of reach (45°, 90°) and two levels of starting separation distances (2", 10") were used for these experiments. Handedness was found to be an insignificant variable affecting performance time ($P > 0.05$), whereas distances traveled, angles of reach and starting separation distances were found to be significant ($P < 0.05$). Linear Regression Models for predicting performance time have been developed using distances traveled, angles of movement and starting separation distance as independent variables. Biomechanical effects, balancing tendency effect and visual search effect were analysed. The performance time of asymmetrical simultaneous reach motions was found to be significantly greater than single-handed reach motions. The variation in time depended on the distances traveled by hands, angles of reach and starting separation distances.

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CHAPTER I

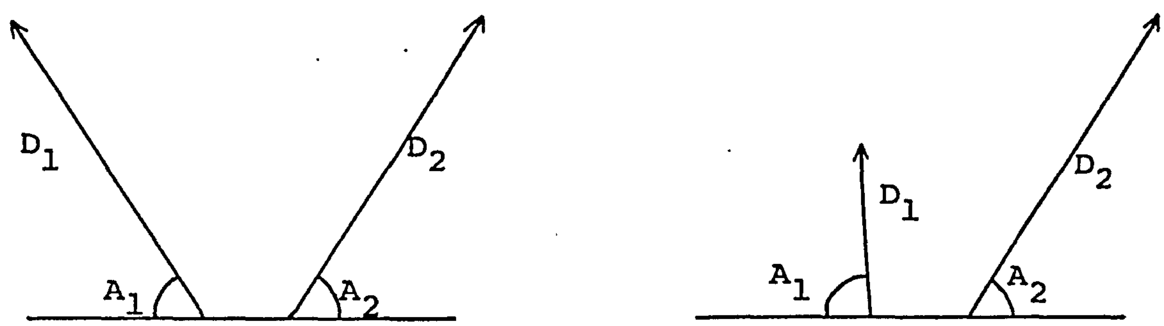
INTRODUCTION

The prediction of human performance time has been used for managing production systems. Accurate findings are necessary so as to obtain proper settings of 'time standards' for a fair performance evaluation, for establishing a better incentive program, to avoid overtaxing the workers, to minimize accidents, to assist production scheduling, work layout design, etc.

In industries, most of the operations are performed by two or more body members, either in symmetrical or asymmetrical fashion, to obtain <u>higher</u> production output, despite the fact that the cycle time of two-hand simultaneous motions is found to be slightly higher than that of one-hand motions. Simultaneous motions have generally been defined in human performance as motions performed by two or more body members, begun and completed at the same time. Symmetrical simultaneous motions refer to those identical motions performed by two or more body members with identical angles and distances traveled in the same plane. Asymmetrical simultaneous motions are those motions which are <u>not</u> symmetrical simultaneous motions (13). Figure 1 shows diagrammatically the symmetrical and asymmetrical

$D_1 = D_2$ $\qquad$ $D_1 \neq D_2$

$A_1 = A_2$ $\qquad$ and/or $\quad A_1 \neq A_2$



(i) Symmetrical Simultaneous Motions

D = distance traveled by 2 hands

A = angle of motion

(ii) Asymmetrical Simultaneous Motions

Figure 1. Symmetrical and Asymmetrical Simultaneous Motions

simultaneous motions.

In studying simultaneous motions, two approaches have been used. One approach is called the 'complete cycle time approach' where complete cycle times are analysed. Each cycle consists of a sequence of elemental motions. The second approach is called the 'elemental time approach' in which each element in a working cycle is analysed.

Some of the earlier researchers used the 'complete cycle time approach'. One main disadvantage in this approach is that the results cannot be applied universally because industrial working operations are numerous and vary considerably among different industries.

The 'elemental time approach' has been considered to be more useful as far as applicability is concerned. This approach has been adopted mainly by the developers of predetermined motion time systems, such as Method Time Measurement (M.T.M.), Work-Factor System and Basic Motion Time Study (B.M.T.). Even though for every system it is claimed that the time measurements have a high degree of accuracy, yet in each system simultaneous motions are handled differently and different time values are assigned. Under M.T.M. no additional time is assigned if the simultaneous motions of concern are classified as 'easy to perform simultaneously' on the other hand, time will be assigned to <u>each</u> hand if it is classified as 'difficult to perform simultaneously', this resulting in doubling the time allowed. The Work-Factor System allows only 50% additional time to those variable time elements, such as complex grasp, preposition and assemblies. Under B.M.T., additional time is allowed when two hands are performing operations simultaneously according to the size (or tolerance) of the object (or target) and the terminal separation distance between the two objects. The time values are given in a table form. The discrepancy of the time values assigned under these systems lies in the fact that each system has a different classification of elemental motions, different research methodologies and different emphasis among the variables of their own choices. Also, for the same reasons, it is difficult to find out which system is relatively accurate. The data on which most of these systems are based are not available in the literature. Moreover, the effects of distances traveled and angles of movement have been found to be significant when performing simultaneous two-hand motions (1, 3, 8, 9, 13). Yet none of these systems offers any special treatment when dealing with asymmetrical simultaneous motions, where the two hands are moving with unequal distances and/or with different angles. The effect of starting separation distance has not yet been looked into as well. Additional study is considered necessary for improving the productivity of industrial systems and also enhancing our understanding of human performance for tasks having asymmetrical simultaneous motions.

This thesis presents an investigation on the effects of the independent variables, namely the angles of reach motions, the starting separation distance and the distances traveled by both hands simultaneously in the horizontal plane, on performance time. The effects of an individual's handedness and learning behaviour on performing simultaneous 'reach' motions are also investigated. The comparisons of simultaneous motions and single-handed reach motions, asymmetrical and symmetrical simultaneous reach motions are presented as well.

CHAPTER II

LITERATURE SURVEY AND OBJECTIVES OF RESEARCH

In this chapter, the present state of knowledge related to simultaneous hand motions is presented and the pertinent information is reviewed.

2.1 Literature on the Two Approaches

(a) Complete Cycle Time Relationship With One Hand

Barnes and Mundel (3) found an increase of 37% in cycle time for two-hand cycles over one-hand cycles. Barnes and MacKenzie (2) conducted another task and found that for two-hand simultaneous motions the cycle time increase ranged from 30% to 40%. Block (6), found that no single constant percentage existed for the relationship of cycle time for two-handed work as compared to that for one-handed work.

(b) Elemental Time Relationship With One Hand

The M.T.M. (11) system provides a simultaneous motion chart in which various combinations of motions are classified as 'NO PRACTICE', 'SOME PRACTICE', or 'DIFFICULT'. No extra time is allowed for simultaneous performance of motion combinations classified as 'NO PRACTICE'. On the other hand, time is allowed for each hand motion when the motion combination is classified as 'DIFFICULT' in which motions cannot perform simultaneously after a long period of practice.

Dyer (7), in a study of the Work-Factor system, stated in his paper that the increase in time for simultaneous motion depended on the complexity of the motion sequence. Wherever variable motion sequences occur, the persons using the Work-Factor system should provide an allowance for simultaneous cycles amounting to 50% of the 'variable time for each hand'. Variable time occurs in complex grasp, preposition and assemblies.

Basic Motion Time study (5) has a separate table which provides additional time for simultaneous motions. The two variables for selecting an additional time allowance from the table are the separation distance between the critical points and the tolerance with which the fingers must be placed to perform the operation.

The literature cited above indicates (i) the non-versatility of complete cycle time approach, (ii) different methods of handling simultaneous motions and different time values predetermined by different systems and (iii) that using one-hand time values to predict two-hand simultaneous motion time is not accurate in every case, as evident from the inconsistent findings among the systems. All these indicate that further investigations are necessary.

2.2 Literature on the Variables Affecting Simultaneous Motions

(a) Visual Effect

Almost all the literature indicates that eye movements play an important role in simultaneous two-hand motions. Barnes and Perkins (4), in studying the operation involving the use of both hands traveled in asymmetrical fashion, the left hand grasped a part from the supply bin with tweezers and carried it to a central position. There the part was transferred to tweezers in the right hand which positioned the part in a machine. Eye movements were recorded and they concluded that 'the two-fixation method would have taken less time than the three-fixation method if the study had been carried on further'. The term 'two-fixation pattern' refers to cycles in which the subject fixed on one of the two critical points (either left or right) and then fixated the other. In this case, the first fixation occurred at the central position and the second fixation at the positioning. The extra fixation in the three-fixation pattern case would be the grasp fixation.

Block (6), in his study, indicates there was no significant cycle time difference between the subjects who consistently used a two-fixation pattern and those subjects who consistently used a three-fixation pattern. There was a slight increase in cycle time for those who used a mixed eye movement pattern. So it seems advantageous to train the subject to use a consistent eye-movement pattern.

The M.T.M. (11) system states that within the area of normal vision certain hand motion can be accomplished simultaneously and outside this area simultaneous operations are difficult to perform. The M.T.M. system defines the 'area of normal vision' as an area approximately 4 inches in diameter at a distance of sixteen inches from the eyes, or a visual angle of about 7 degrees to the right and left of the central line of sight.

Lynch (10) also states that if the two parts to be grasped simultaneously are separated by a distance of more than 3 inches, 'the eyes cannot focus on both 'pick-ups' at once and thus the simultaneous reach-grasp is slowed down by the necessity of shifting the point of focus of the eyes'.

(b) <u>Angle Effect</u>

Barnes and Mundel (3), in their study of simultaneous, symmetrical hand motions, by pushing a carriage back and forth along fixed slides in the positions of 90, 60, and 0 degree plane angles, found that, on the average, the most rapid cycle time occurred when the paths of the hands both made angles of 60 degrees with the plane in front of the operator's body. Motions where the aforementioned angle was 90 degrees required 5% more time, where the angle was 30 degrees, 3% more time and where the angle was 0 degrees, 9% more time. They also concluded that with both terminal points and paths of motion fixed, times for hand motions are different from those obtained when terminal points alone are fixed'. It was suggested that when the slides are used, no visual direction is required to perform the motions and the optimum conditions are primarily determined by the arm muscles of the operator. In another experiment with the pursuit board, where only the two terminal points were fixed, the operators had to locate the terminal points visually each time they moved their hands. They suggested that with the pursuit board and the 90 degree arrangement, the greater ease and less fatigue occasioned in visually determining the location of the two most distant terminal points far outweighed the possible greater muscular ease of working at the other plane angles.

In Konz's report (9), he mentioned that in France, Bouisset, Monod and Maville had made an investigation on the angle and distance effects upon two-hand symmetrical motions. The subjects were required to perform under 3 conditions:

(1) 90 degrees and 30 cm. (12 inches)

(2) 90 degrees and 15 cm. and

(3) 30 degrees and 30 cm.

The subjects were required to move a 200.0 gm. weight in each hand while the cardiac frequency was measured. By contrasting the sum of the excess pulsation in relation to the level at rest, they concluded that there was significant difference between condition 1 and conditions 2 and 3, but not between 2 and 3 alone; reduction in distance may compensate for the angle effect.

Barnes and Balch (1) in their 'study of symmetrical and asymmetrical simultaneous hand motions in 3 planes', stated that the 2 subjects were required to move (grasp, transport loaded, release load, and transport empty) small parts from a bin located at 90° (in which both hands moved straight ahead), 0°R (in which both hands moved directly to the right supply bin) and 0°L (in which both hands moved directly to the left supply bin) and 0° opposite (in which the right and left hands moved to the right and left supply bins respectively) and in planes of 3 different heights. They found that the fastest learning angle is 90°, when the total cycle time was considered. For the 'transport empty' (or Reach) elemental time, the least time occurred at an angle of 0°L. Compare this with other angles: 0°R took 8% more time, 0° opposite took 11% and

90° took 15%.

(c) Distance Effect

All literature indicates that distance is a significant variable in performing simultaneous motions. However, when the distances traveled by each hand were different, Raphael and Clapper (13), observed the existence of 'balancing tendency' between the right and left hands. The hand travelling with shorter distance tended to slow down while the other hand, travelling at a longer distance, tended to speed up somewhat to match the other hand. They found out that the cycle times for unequal distances for simultaneous motions fell between the allowed time for each hand given by M.T.M. system data card.

All systems are treating asymmetrical simultaneous motions as though the same as symmetrical ones. No special treatment, nor different time, was given to this kind of asymmetrical simultaneous motion. No other literature on this subject is available at this time. What exactly are the causes of this balancing tendency does not seem to be known. Further investigation on this subject is necessary.

(d) Terminal Separation Distance Effect

In B.M.T. (5), it was found that when the terminal separation distance is greater than 3 inches, eye movement is necessary so that the hands can perform simultaneously.

It was concluded that separation distance is a significant variable. Hassan and Block (8) in their two-hand simultaneous positioning experiment had found that terminal separation distance has a linear effect upon performance time within experimental limits.

Niebel, Kassab and Noll (12) performed a symmetrical simultaneous positioning task using 2 subjects and had found that the positioning time (T) had an exponential relationship with the terminal separation distance (D) as follow:

$$T = 14.1\ D^{0.0864}$$

Since the terminal separation distance is a function of the angle, the starting separation distance and the distances travelled by 2 hands, a study of terminal separation alone is not sufficient.

2.3 Objectives of Research

The objective of the present research is to conduct a comprehensive study of the significant factors, as evident from the literatures, which may affect simultaneous motions. In order to do that the following will be studied:

1. the effect of learning behaviour upon performing simultaneous reach motions.

2. the effects of distances travelled by both hands, the angles of reach motions and the starting separation distance upon performance time.
3. the variations, if any, in performance times between right-handed and left-handed subjects.
4. the variations in performance times between simultaneous reach motions and single-handed reach motions.

2.4 Methodology of Research

This research is divided into three studies. The objectives of Study #1 are (i) to investigate the learning behaviour upon performing simultaneous motions (ii) the level of significance of the variables. Hence proper experimental procedures and analysis can be devised for Studies #2 and #3. Study #2 will reflect the objectives as outlined in section 2.3, numbered 2 to 4. Study #3 deals with preferred single hand reach motions. This study will compare with study #2.

CHAPTER III

EQUIPMENT AND EXPERIMENT DESIGN

3.1 Introduction

This chapter describes in detail the equipment set-up employed in this research. A general experimental procedure common to all three studies is presented, but the detailed experimental design will be discussed separately under each study.

3.2 Equipment Set-up (see Appendix A.0, Figures A1, A2)

The equipment consists of 3 units - a simultaneous-motion measurement unit, a time-recorder unit and a paper-tape punch unit.

(a) Simultaneous-Motion Measurement Unit

A special simultaneous motion measurement unit in the shape of a rectangular wooden box, having dimensions of 61.5" long x 20" wide x 6" high fastened on top of a 32" high steel frame, was designed and built for the experiment. Two 18" long x 1.5" wide x 3/8" high plastic rods marked with graduations from 1" to 13", were located on top of the box. Two activating switches with buttons of 13/16" in diameter were fastened to the closed end of the rods in a fixed position. Another two similar switches for terminating the cycles were positioned in the slot opening of the rods and were capable of sliding up and down along the rods. The two rods were also capable of sliding left and right along the slot opening of the box (see Appendix A.0, Figure A3). A built-in buzzer, with a delay buzz of one second after two terminating switches were pressed, was located at the left hand side of the box.

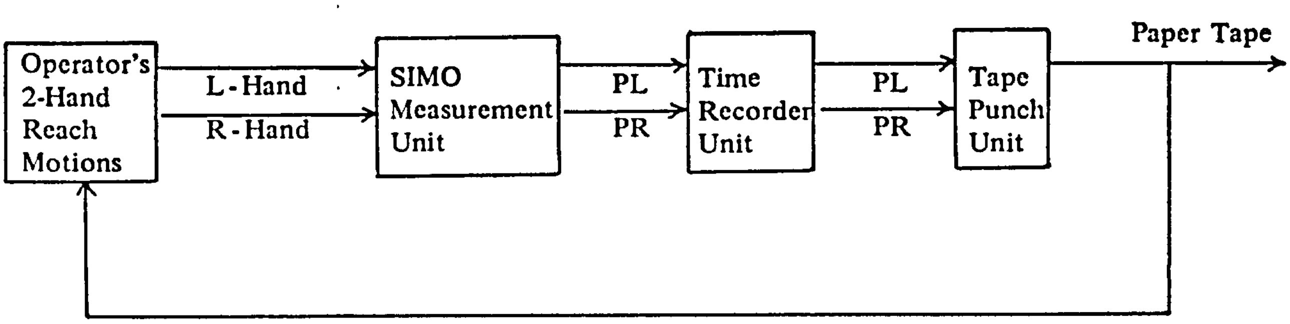
The switches were very sensitive, even a light touch would be enough to activate the system so that no force would be necessarily applied by the operator. A plastic sleeve, located on top of the switches, served as a guard to prevent the subjects from pressing the edge of the top buttons of the switches and to ensure that the subjects could press the buttons only with their finger tips but not the lower part of their index fingers.

Also each rod was fastened by a plastic nut located beneath the activating switch and by two screws, for securing purposes, against the edge of box. A thin plastic angle indicator marked with degree graduations from 0° to 180°, was located under the nut.

(b) <u>Time-Recorder Unit and Tape-Punch Unit</u>

The time-recorder unit was designed and built in the university. The elapsed time for each hand, measured in milliseconds, could record in this unit and transfer immediately to a Facit paper tape punch unit. This tape was later converted into computer data cards for the analysis.

The block layout diagram of the equipment is shown in Figure 2.



SIMO = Simultaneous Motion
PL = Performance time for the left hand
PR = Performance time for the right hand

Figure 2. Block Layout Diagram of the Equipment

3.3 Experimental Design

(a) Variables

The dependent variable for this research is the performance time (PT) which is defined as

PT = Max (PR, PL)

where PR is the performance cycle time of the right hand upon performing 'reach' motion, and PL is the performance cycle time of the left hand upon performing 'reach' motion.

The performance cycle time is defined as the time taken for performing reach motion starting from activating the switch and ending by pressing the terminating switch.

The independent variables are:

1. Right-hand distance (R) - distance travelled by the right hand, measured from the activating switch to the terminating switch of the right-hand rod, center to center.
2. Left-hand distance (L) - distance travelled by the left hand measured from the activating switch to the terminating switch of the left-hand rod, center to center.
3. Direction of move (A) - the angles measured with respect to the horizontal line connecting two activating switches which are the same for both left and right hand sides.
4. Starting Separation distance (S) - distance between the two activating switches.
5. Handedness (HAND) - is the handedness of either right-handed or left-handed subjects.

Figure 3 depicts the pictorial view of the 4 independent variables. The response times for both right hand and left hand are measured in milliseconds simultaneously.

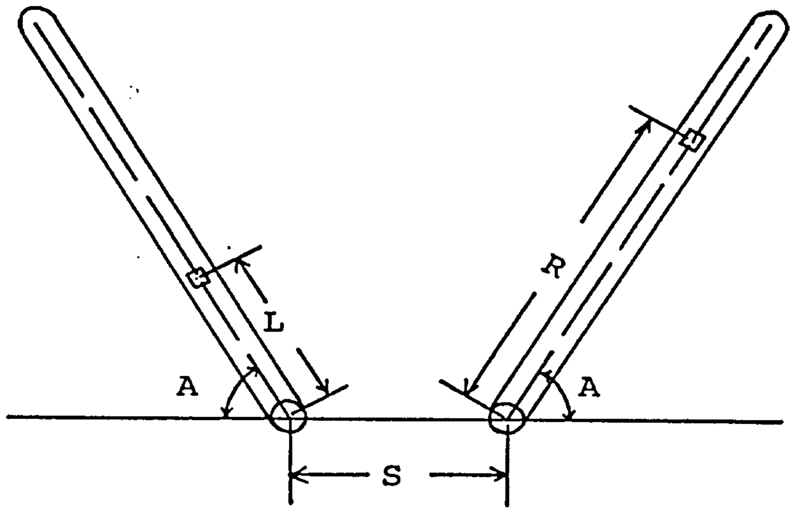


Figure 3. Picturial view of the 4 independent variables.

(b) Hypotheses

The hypotheses for the present research are as follows:

1. There is a significant difference in performance time between single-handed reach motions and simultaneous reach motions - either symmetrical or asymmetrical.
2. The performance time (PT) can be represented by the expression

   PT = f(R, L, A, S)

3. There is no significant difference between right-handed subjects and left-handed subjects upon performing single-handed reach motions and simultaneous reach motions - both symmetrical or asymmetrical.

(c) Procedure

The present research was conducted in one of the Industrial Engineering laboratories having normal room temperature and adequate illumination. A pilot experiment, referred to here as study #1, was conducted prior to studies #2 and 3. Study #2, concerned with simultaneous motions, was conducted at a later date and was followed by study #3 which dealt with single-handed reach motions.

All subjects required to perform reach motions which were comprised of the following steps:

1. Press activating switch(es) using index finger(s).
2. Reach for terminating switch(es).
3. Press terminating switch(es).

After completing the above, the subject moved the hand(s) back to activating switch(es) at his own pace and would be ready to start the next cycle after hearing the buzz sound. The parenthesis represents 2-hand simultaneous motions.

A subject's response can be represented by the following block diagram.

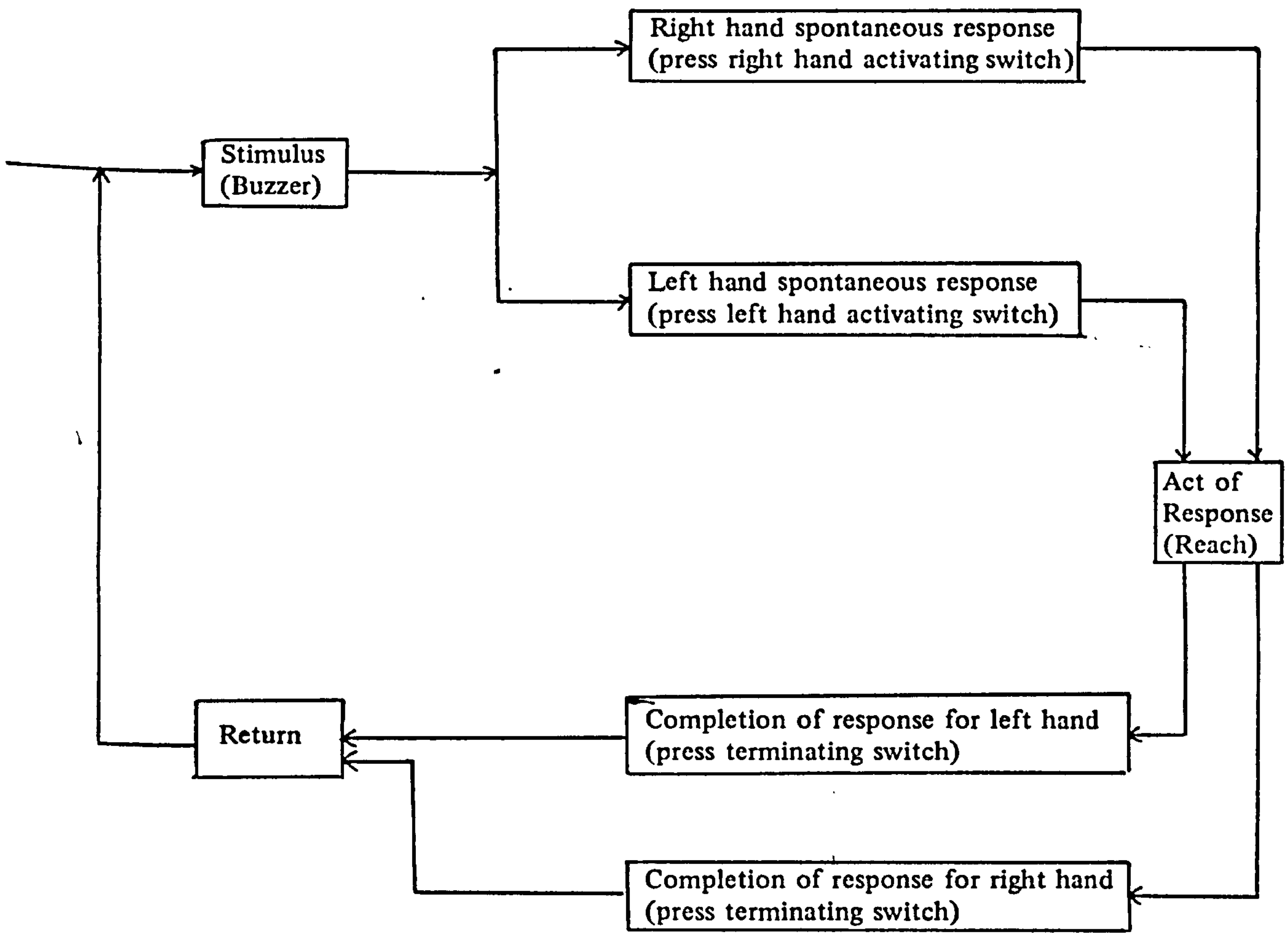


Figure 4. Response Block Diagram
- Reach Motion.

(d) Instructions to the Subjects

To standardize the method of reach and to accommodate differences due to individual physical features, the following instructions were given to the subjects before starting the experiment.

1. The subject was instructed to sit up straight in front of the 'Simultaneous Reach Motion' equipment with the

center line of his body aligned approximately with the center of the equipment.

2. The subject was instructed to rest his index finger(s) on top of the activating switch(es) and to perform the reach motions as fast as he could after hearing the buzzer sound.
3. The subject was instructed not to move his head or shoulder while performing the reach.
4. The subject was instructed to repeat the motion immediately if he failed to press the terminal buttons.

CHAPTER IV

STUDY #1 - LEARNING BEHAVIOUR OF ASYMMETRICAL SIMULTANEOUS REACH MOTIONS

4.1 Introduction

The objectives of this study were (1) to determine the number of learning cycles needed by the subject to perform so that he could be considered to be in a fully learned state; (2) to determine the significance of each level of the variables for the preparation of subsequent studies.

4.2 Experiment

(a) Experimental Conditions

The levels of the variable included in this experiment were as follows:

	Variables	Level 1	2	3	4	5
1.	Right hand distance traveled (R)	3"	9"			
2.	Left hand distance traveled (L)	3"	9"			
3.	Angle of movement (A)	30°	45°	60°	75°	90°
4.	Starting separation distance (S)	2"	6"	10"		

There were a total of 60 conditions (= 2 x 2 x 3 x 5). Appendix B.0, Table B1, shows the use of ordered condition number to reflect the level of each variable and the sequence of experiments performed by each subject.

(b) Choice of Levels of R, L, A, S

The levels were so chosen because they are commonly found in work design and within the maximum reach of the average worker. Within this region, hand motions can be performed without moving the head and shoulder. Only 2 levels of distance traveled (R, L) were used essentially to minimize the time and cost of the experiment.

(c) Choice of Subjects

Five right-handed male subjects of ages ranging from 23 to 26 were chosen randomly among the university students. All subjects were in good physical condition. Each subject was paid $10.

(d) Methodology

The conditions for each subject to perform were randomized and randomly assigned to him by a Plan Procedure of the SAS computer package. The order of performance of each condition, for all 5 subjects, is shown in Appendix B.0, Table B1.

The duration of the experiment was approximately 4 1/2 hours. Each condition took 3 minutes. A Universal Timer was used to keep track of the time. Each subject was allowed a 15-minute break after performing every 10 conditions and a brief intermission of 1/2 min. to 1 min. during a change of conditions. The whole experiment took about 4 1/2 hours to be completed in one session.

(e) Data Collection

For a duration of 3 minutes per condition, 70 to 130 cycle times were collected after screening out tape-punch errors by a SAS computer program. Appendix B.1 is the computer program used to input the data and screen out the errors.

4.3 Data Analysis

(a) Learning Effect

The learning effect is categorized into 2 parts, viz. (1) learning from error (2) learning without error.

1. Learning from error

An error occurred when the subject failed to press the terminating switches and he had to repeat the motion to complete the cycle. The resulting time became much greater than the average mean time (see Appendix B.2). From the collected empirical data it was observed that the use of 2 standard deviations plus the mean as an upper bound would help to identify any obvious errors which have values greater than this upper limit. To be objective, any cycle times which are greater than 2 standard deviations plus the mean will be considered as errors. Also a safeguard of 4 standard deviations from the mean ($\mu-4\sigma$) for the lower limit was used to screen out the possibility of digit overflow in the tape punch, which might give an extremely low reading. (The tape punch can punch only 3 digits per cycle time. Any cycle time greater than 999 will give an overflow.) The occurrence of errors was about 6% per condition and the overflow occurred only 1 or 2 times per experiment.

2. Learning without error

The effect of learning after excluding the error data was also studied. A computer program was written to exclude the errors. This is shown in Appendix B.1.

(b) Analysis Model

A randomized factorial mixed nested model was used for the analysis of performance time (PT). The model is as follows:

$$\begin{aligned} PT_{ijklmn} = \mu &+ R_i + L_j + S_k + A_\ell + O_m + (R*L)_{ij} + (R*S)_{ik} \\ &+ (R*A)_{i\ell} + (R*O)_{im} + (R*L*S)_{ijk} + (R*L*A)_{ij\ell} \\ &+ (R*L*O)_{ijm} + \ldots + (R*L*S*A)_{ijk\ell} + \ldots \\ &+ (R*L*S*A*O)_{ijk\ell m} + \varepsilon_{n(ijk\ell m)} \end{aligned}$$

where R_i = distance traveled by the right hand, i = 1, 2

for R_1 = 3", R_2 = 9"

L_j = distance traveled by the left hand, j = 1, 2

for L_1 = 3", L_2 = 6"

S_k = initial separation distance, k = 1, 2, 3

for S_1 = 2", S_2 = 6", S_3 = 10".

A_ℓ = Angle of movement for both hands, ℓ = 1,2,3,4,5,

for A_1 = 30°, A_2 = 45°, A_3 = 60°, A_4 = 75°,

A_5 = 90°.

O_m = Subjects, m = 1, 2, 3, 4, 5.

$\varepsilon_{n(ijk\ell m)}$ = residual including cell repetition and the third and fourth order interaction terms.

$PT_{ijk\ell mn}$ = performance time of the n^{th} observation for the i^{th} level of R, j^{th} level of L, k^{th} level of S, ℓ^{th} level of A and m^{th} level of subject.

4.4 Experimental Results and Discussion

(a) Learning Behaviour

The experimental data for each condition per subject was implemented by the use of Statistical Analysis System (SAS) computer package to generate the following results.

1. The overall learning curves including errors (Appendix B.2).
2. Error learning curves (Appendix B.3).
3. Learning curves without errors (Appendix B.4).

4. Regression analysis and slope tests in order to see if learning exists (Appendix B.5).
5. Duncan's multiple range tests to test the means of 20 data points per group in order to find the learning cycles necessary for each condition (Appendix B.6).
6. Utilizing the computer outputs (Appendix B.5 and B.6) a learning table was constructed for each condition per subject (Appendix B.0, Table B2).

From the above results we observe the following:

1. The overall learning curves indicate very little learning was necessary to perform simultaneous reach motions and errors occured only in small frequency (about 6% per condition).
2. The error learning curves indicate there was no learning from errors. A 'Run Test' was used to test the randomness of the errors and they were found to be at random.
3. The no-error learning curves indicate again very little learning was necessary for the task of concern.
4. The learning table confirms that the number of learning cycles needed, though varies from condition to condition among the subjects, is small with no more than 80 cycles.

(b) Significant Levels of Variables

An Expected Means Square (EMS) Table (Appendix B.0, Table B3) was constructed to determine the tests of variables and interaction terms to be performed in the analysis of variance. The effects of the variables then were tested accordingly by the ANOVA procedure of the SAS program package using the analysis model mentioned in section 4.3.b. The results are given in Appendix B.7. It was found that all the main effects were significant ($P<0.05$). The interaction terms R*L and R*L*A were also significant ($P<0.05$).

To test the significance of the levels (see Appendix B.8) for each variable it was found that

(i) For the angles of movements there was no significant difference between A = 30° and A = 45°, also no significant difference between A = 60° and A = 75°. ($P<0.05$) Maximum PT occurred at A = 30° or 45° and minimum at A = 90°.

(ii) For initial starting separation distance all levels were significantly different from each other ($P<0.05$). Maximum PT was at S = 10" and minimum PT at S = 2".

4.5 Conclusions

From the above analysis, we can draw the following conclusions:

1. The number of learning cycles necessary for performing simultaneous reach motions were found to be small and differed from condition to condition among subjects. The number of cycles needed ranged from zero to a maximum of 80 cycles. Therefore a subject after performing 80 cycles can be considered to be in a fully learned state.
2. All main effects (R, L, A, S) and two interaction terms (R*L, R*L*A) were found to be significant ($P<0.05$). This indicates that the study of asymmetrical simultaneous motions should include all the significant main effects as found above. And the existence of interaction terms indicate that a factorial design is desirable.

CHAPTER V

STUDY #2 - ASYMMETRICAL AND SYMMETRICAL SIMULTANEOUS 2-HAND REACH MOTIONS

5.1 Introduction

The objectives of this study were to investigate (1) the effects of distances traveled by both hands, the angles of reach and the starting separation distance upon performance time, (2) the variations in performance times between right-handed and left-handed subjects and (3) the difference between asymmetrical and symmetrical simultaneous 2-hand motions.

5.2 Experiment

(a) Experimental Conditions

The levels of the variables included in this experiment were as follow:

Variables	Level 1	2	3	4
R	3"	6"	9"	12"
L	3"	6"	9"	12"
A	45°	90°		
S	2	10		
H (Handedness)	Right	Left		

There were a total of 64 conditions (= 4 x 4 x 2 x 2) per subject. Appendix C.0, Table C1 shows the levels of variables in accordance with the orders of their condition numbers.

(b) Choice of Levels of R, L, A, S

The reason for having 4 levels in R, L was to provide a closer look at the effects of asymmetrical simultaneity upon performance time.

From Study #1 it was found that performance time is maximum at A = 90° and minimum at A = 30° or 45°; whereas S is maximum at 10" and minimum at 2". The maximum and minimum levels of A and S were chosen for this study.

(c) Choice of Subjects

A total of 14 subjects were employed to do the experiment. Each received $15. All subjects were asked to sign their names using their preferred hands. Four right-handed and four left-handed subjects were chosen in random first. An ANOVA analysis was done immediately after the experiment. The result indicated that handedness was not a significant factor ($P<0.05$). With an addition of 3 more right-handed subjects and 3 more left-handed subjects the insignificance of handedness remained unchanged. Therefore a final total of 7 right-handed and 7 left-handed subjects were chosen to perform the experiment.

(d) Methodology

The experimental conditions were randomized for each subject. Each subject was instructed to perform approximately 500 cycles before starting the experiment. The selective conditions chosen for the practice period were conditions #1, 9, 22, 36, 44, 47, 48, 52, 61, 61 (see Appendix C.0, Table C1). Before starting each condition, the subjects were instructed to practice on that condition for about 20 cycles. The duration of the experiment under each condition after practice, took about 1.5 minutes to 2 minutes depending on the condition. The longer the distance and separation, the longer the duration. The whole experiment took about 6 1/2 hours to complete.

(e) Data Collection

Approximately 60 data points were collected per condition. After screening out the tape punch errors, the data points were stored on magnetic tape. A computer program to input the data into the magnetic tape is shown in Appendix C.1. Errors were excluded from the analysis subjected to the criteria of 1 standard deviation from the mean ($\mu+\sigma$) on the upper bound and 2 standard deviation from the mean ($\mu-2\sigma$) on the lower bound.

The reason of choosing 1 standard deviation as the criteria because all the subjects were instructed to repeat the cycle when they failed to press the terminating switches so that the error cycle time would be large enough to identify and be able to exclude from the analysis. But the error's high cycle-time value also widened the bounds on the true mean. In some cases 1 standard deviation from the mean was necessary so that the errors could be excluded.

5.3 Analysis Model

With the considerations of handedness, fixed and random variables and the existence of interaction terms, a randomized mixed-nested factorial design model was used for the analysis of simultaneous motions performance time (PT). The model's expression is as follow:

$$PT = \mu + \sum^{\text{all}} R_i | L_j | A_k | S_l | O_{p(m)} | H_m + \varepsilon_{n(ijklmp)}$$

where μ = constant

$O_{p(m)}$ = Subjects nested within handedness, P = 1, 2, 3, 4, 5, 6, 7

and R, L, A, S, H are the same as defined before, having the levels of 4, 4, 2, 2, 2 respectively. $\varepsilon_{n(ijklmp)}$ is the residual, including cell repetitions. The summation term represents the sum of all first order main effects and interaction effects. A complete listing of all the combinations under this term is shown in Appendix C.2 under the SAS ANOVA procedure output.

5.4 Data Analysis

After excluding the errors, 20 data points per condition were used for the analysis. An expected mean squares (EMS) table was constructed as shown in Appendix C.0, Table C2. A SAS computer package was used to compute the ANOVA and conduct the tests of all main and interaction effects, with the information provided from the EMS table. Graphs were plotted to illustrate the relationships of performance times with various significant effects. Asymmetrical and symmetrical simultaneous motions were analysed. Prediction models were also developed. The results will be presented in the next section.

5.5 Experimental Results and Discussions

In this section the experimental results and discussions are presented in two parts: (a) General simultaneous motions which includes both symmetrical and asymmetrical simultaneous motions, (b) Symmetrical simultaneous motions. Asymmetrical simultaneous motions (ASYM-SIMO) refer to those conditions of which R $\neq$ L and symmetrical simultaneous motions (SYM-SIMO) refer to those conditions which are not asymmetrical. SIMO is used to denote simultaneous motions.

(a) General Simultaneous Motions

1. Normality Test

A normality test of the sample distribution for each condition per subject was performed by the KSLTEST procedure of the SAS computer package. A sample of the computer results is shown in Appendix C.3. The overall results for performance time PT indicate that 90.07% of the 896 conditions are normally distributed at $P>0.05$ and become 100% if P has chosen to be 0.01%.

2. ANOVA

Twenty data points per condition per subject were used for the ANOVA as shown in Appendix C.2. The result indicates that at $P<0.05$ the performance time (PT) can be expressed as PT = f(R, L, A, S, R*L, R*A, A*L, R*L*A, L*HAND, L*A*HAND, A*S*HAND, R*L*A*HAND) where R, L, A, S are the same as defined before and HAND is the handedness (H) of the subject. The PT expression reduces to PT = f(R, L, A, S, R*L, R*A, A*L, R*L*A) at $P<.01$.

From the results it can be seen that interaction terms do exist in performing simultaneous 2-hand reach motions. Even though handedness (HAND) alone has found to be insignificant ($P>0.05$) and yet it interacts with other main effects. Furthermore, at $P<0.01$, the interaction terms with handedness (HAND) disappear. In order to investigate how significant the variables are, an analysis of the component variances of all the significant effects is performed. The detailed computation of component variances is shown in Appendix C.2(a) and the result is summarized as follow:

Subject	Variance	=	30.85%
R	Variance	=	23.50%
L	Variance	=	20.52%
S	Variance	=	9.95%
A	Variance	=	3.19%
Sub-total		=	88.01%

R*L	Variance	=	3.70%
R*A	Variance	=	1.06%
L*A	Variance	=	1.84%
R*L*A	Variance	=	2.91%
Sub-total			9.51%

R*L*A HAND	Variance	=	1.07%
L*A*HAND	Variance	=	0.43%
S*A*HAND	Variance	=	0.47%
L*HAND	Variance	=	0.51%
Sub-total			2.48%

From the results it can be seen that the total variance contributed by the interaction terms with handedness is only 2.48% which is very small as compared to the main effects. The subject variance accounts for the largest 30.85% indicates there is a big difference among the subjects upon performing simultaneous 2-hand reach motions. To investigate further the sensitivity of the interaction terms with handedness in the prediction equation, a multiple regression was performed.

3. Multiple Regression Analysis

A multiple regression analysis was performed using the GLM procedure of the SAS Computer package. The computer outputs are shown in Appendix C.4 and Appendix C.5. The results are summarized here as follow:

With handedness interaction terms

PT = 257.76 + 34.19 R + 31.79 L - 61.77 A + 49 S
+ 10.66 R*L + 26.38 R*A + 32.87 L*A - 15.09 R*L*A
- 0.025 R*L*A*HAND - 6.65 L*A*HAND + 1.31 A*S*HAND
+ 3.15 L*HAND -----------(1)

Total data = 17920 , r^2 = 0.465945, significant level of fit = 0.0001.

Without handedness interaction terms

PT = 253.34 + 34.19 R + 36.51 L - 58.82 A
+ 51.95 S + 10.66 R*L + 26.38 R*A
+ 22.89 L*A - 15.13 R*L*A --------(2)

Total data = 17920, r^2 = 0.459247, significant level of fit = 0.0001.

Comparing the two expressions, with a little sacrifice in the goodness of fit (difference in R^2 = 0.006698), expression (2) is much simpler. Again the effect of handedness interaction terms is found to be <u>not</u> significantly affecting the model.

4. <u>Test of Means</u>

Duncan's multiple range test was used to test the average means of 14 subjects for each condition. The computer output is shown in Appendix C.6 and the results are being utilized in plotting the graphs. Duncan's tests also employed to test the level of significance of the main effects and the computer output is shown in Appendix C.7. The results indicate that performance time (PT) is proportional to R, L, S. As for the angle of reach (A), higher PT values occur at A=45° and become smaller at A=90°. In general, all levels of the variables are found to be significantly different from each other (Appendix C.7).

5. <u>Limiting-hand Effect and Visual Effect</u>

Using the average means of 14 subjects the graphs were plotted as shown in Appendix C.0, Figures C1 to C10. While keeping A and S constant, by varying either R or L the graphs show a close resemblance for a specific A and S (Figures C5 and C8). However the response performance time (PT) behaves differently at different angle of reach. In Figures C1 and C2 PT increases as R or L increases at A=45°

and S=2", same for Figures C6 and C7. When A=90° and S=2" we have a different response pattern (see Figures C3 and C4). To analyse the difference in response time at different angles one has to bear in mind the visual effect and the principle of limiting motions. Obviously at A=45° a visual search is necessary to assist simultaneous 2-hand reach motions, while at A=90° very little visual search is necessary. According to the principle of limiting motion, performance time is said to be limited by the hand which travels a longer distance. In other words, the hand travels at a shorter distance serves as a 'slave' hand to the other hand which travels at a longer distance. In Figures C1 and C2 (A=45°), the existence of visual search coupling with limiting hand motions will tend to increase the performance time as R or L increases. As in Figures C3 and C4 in which both hands travel straight ahead (A=90°), in this case only limiting motions prevail. For example, in Figure C3 when L=3" and varies R, left hand will be limited by the right hand which travels progressively a longer distance than the left hand. When L is at a constant of 6", the first two data points are not significantly different from each other (See Appendix C.6 for conditions 21 and 22) because, for the first data point, PT is limited by the left hand at 6"; as for the second data point both hands travel at 6" and PT is limited by the same distance of 6" also. Same reasoning can be applied for Figure C4.

With A=45° at different S the resulting curves exhibit similar pattern except that the curves are being shifted upward due to the increase in initial separation distance (compare Figure C1 and C6, C2 and C7). However for A=90, S=10 (Figure C9 and C10) the curves behave a little different than in the case where A=90°, S=2 (Figures C3 and C4), this can be explained because as the initial separation increases, the separation distance at the terminal points also increases, and visual effect can no longer be ignored completely.

In summary, it is evident from the graphs that ASYM-SIMO performance time is governed by the limiting hand which travels at a longer distance than the other hand. PT will increase as either R or L increases.

Visual effect also plays an important part in determining SIMO performance time. Visual effect is minimum when both hands travel straight ahead (A=90°) and initial separation distance is small (S=2"). This is clearly demonstrated in Appendix C.0, Figures C3 and C4 which indicate the dominance of the limiting hand. The distance traveled by the slavery hand (the hand travels at a shorter distance) does not affect very much the resulting performance time as compared to other motions in which the limiting hand travels at the same distance. The effect of limiting hand principle without visual effect is illustrated in the Tables 1(a) and 1(b).

From Table 1(a) and (b) it can be seen that the difference among various conditions under the same limiting-hand group are small and most of them are not significant under Duncan's means test ($P>0.05$).

However when the angle of reach changes from 90° to 45°, visual effect can no longer be neglected. SIMO performance time (PT) will then govern by both limiting hand effect and visual effect. From the graphs in Appendix C.0, they reveal the following.

(i) As evidence from Figures C1, C2, C6 to C10, even though limiting hand effect exists in every case, but with additional time necessary for visual search, SIMO PT increases as the visual effect becomes more dominant.

(ii) Visual effect is most dominant at A=45°, S=10" and is least dominant at A=90°, S=2" as evidence by the change of slope of the curves under the same limiting distance.

6. Visual Search Strategy

Since visual effect plays an important role in SIMO performance time, further analysis on this effect is

A = 90° , S = 2"

Limiting Hand Distance	Code	R	L	Mean	Mean Difference (1)-(2), (3), (4)	Significance $P < 0.05$	Mean Difference (2)-(3), (4)	Significance $P < 0.05$	Mean Difference (3)-(4)	Significance $P < 0.05$
6"	(1)	3	6	419.92						
	(2)	6	6	413.57	6.36	NS				
9"	(1)	3	9	494.54						
	(2)	6	9	491.56	2.98	NS				
	(3)	9	9	484.18	10.36	NS	7.38	NS		
12"	(1)	3	12	520.51						
	(2)	6	12	540.50	- 19.99	S				
	(3)	9	12	542.45	- 21.94	S	- 1.95	NS		
	(4)	12	12	559.30	- 30.79	S	- 18.8	S	- 16.85	S

Table 1(a): Limiting Hand Effect – With Constant Left-hand Distance Travel (L).

A = 90°, S = 2"

Limiting Hand Distance	Code	R	L	Mean	Mean Difference (1)-(2), (3), (4)	Significance P < 0.05	Mean Difference (2)-(3), (4)	Significance P < 0.05	Mean Difference (3)-(4)	Significance P < 0.05
6"	(1)	6	3	420.55						
	(2)	6	6	413.67	6.98	NS				
9"	(1)	9	3	492.71						
	(2)	9	6	466.79	25.92	S				
	(3)	9	9	484.18	8.53	NS	- 17.39	S		
12"	(1)	12	3	551.19						
	(2)	12	6	565.77	- 14.58	NS				
	(3)	12	9	547.28	3.91	NS	18.49	S		
	(4)	12	12	559.30	- 8.11	NS	6.47	NS	- 12.02	NS

Table 1(b): Limiting Hand Effect – With Constant Right-hand Distance Travel (R).

necessary. Due to the nature of this experiment, the only way to explore the visual effect is to investigate the frequency of occurrence of the right-hand time (PR) greater than the left-hand time (PL) or vice versa. A visual search frequency table is constructed (See Appendix C.0, Table C.3) to summarize the frequency and mean performance time in a 3-dimensional matrix for both right-handed subjects and left-handed subjects, and the combination of the two as well. The table reveals one important aspect that there exists a pattern in visual search when performing SIMO. The significant findings from this table are summarized as follow:

(i) When the ratio of P/L = 3 (or 1/3) the subject has a tendency that the hand traveling a shorter distance will press the button first and then follow by the other hand which travels at a longer distance. In other words the performance time for the hand pressing the terminating button first is less than the other hand which travels longer distance, even though the time difference between the two hands is comparatively small (See Appendix E.1).

(ii) When R/L = 1 (symmetrical SIMO) the combined frequencies of pressing the terminating buttons by each hand are close to each other, that is, equal frequency of occurrence between PR>PL and PR<PL.

(iii) When $R \neq L$ and $R/L \neq 3$ or 1/3 there is no consistent strategy employed by the subjects. The preference is entirely depended upon the individual.

In order to facilitate the discussion on visual search strategy the following definitions are used:

$F_r(PR>PL)$ = the frequency of occurrence of PR>PL for the right hand

$F_\ell(PR>PL)$ = the frequency of occurrence of PR>PL for the left hand.

where

PR = performance time of the right hand

PL = performance time of the left hand.

(i) Deterministic visual search (DVS) : refers to $F_r(PR>PL)$ is at least '2 times greater' than $F_\ell(PR>PL)$ or vice versa, excluding F(PR=PL).

(ii) Probabilistic visual search (PVS) : refers to the visual search strategy which is not deterministic.

The reason of choosing '2 times greater' is because even in the worse case where F(PR=PL)=8.6% out of 280 cycles, the strategy can still be deterministic if and only if either $F_\ell(PR>PL)$ or $F_r(PR>PL)$ accounts for 61% (171/280) of the total cycles per condition, which is more than half of 280 cycles.

To investigate which strategy is more efficient upon performing SIMO it is necessary to compare the two strategies under the same condition. Due to the limitation of this study, which is not designed to investigate the visual effect, only those conditions which have different strategies employed by the right-handed subjects and left-handed subjects can be utilized for comparison purposes. These conditions, obtained from Appendix C.0, Table C3, are summarized in Table 2.

Exp. Condition				Strategy		Performance Time	
				Subjects		Subjects	
R	L	A	S	R-Hand	L-Hand	R-Hand	L-Hand
3	3	45	2	PVS	*DVS	346.12	327.24
3	6	45	2	*DVS	PVS	427.84	457.09
6	6	45	2	PVS	*DVS	476.72	473.91
9	6	45	2	PVS	*DVS	515.87	504.09
3	12	45	2	*DVS	PVS	518.23	519.43
6	6	45	10	PVS	*DVS	551.27	520.03
6	12	45	10	*DVS	PVS	612.84	628.16
9	9	90	10	PVS	*DVS	607.56	547.07
12	12	90	10	PVS	*DVS	623.76	613.74
6	6	90	2	DVS	*PVS	439.00	388.14
6	9	90	2	*DVS	PVS	474.39	508.74
12	12	90	2	PVS	*DVS	603.02	515.74

*indicates the more efficient strategy

Table 2: The Visual Search Strategy Efficiency Table.

The table indicates that (i) deterministic visual search strategy (DVS) is more efficient when visual search is required upon performing SIMO (that is A=45° and/or S=10") (ii) DVS is also more efficient when performing ASYM-SIMO (iii) there seems to be a little evidence that PVS may be more efficient when no visual search is required upon performing a SYM-SIMO (row 10 in Table 2). However since there is not enough information to confirm this, further investigation is necessary. The implication of the above results seems to suggest that it is advantageous to train the subject to use a deterministic visual search strategy.

7. $R_iL_jA_kS_\ell$ and $R_jL_iA_kS_\ell$ Relationship

Table 3 is constructed to illustrate the relationship of $R_iL_jA_kS_\ell$ and $R_jL_iA_kS_\ell$ upon performing ASYM-SIMO.

The table shows that only 50% of the total comparisons are significant ($P<0.05$) (See Appendix C.6). Moreover the magnitude of PT difference is considerably small (maximum difference 30.68 ms or 5.57%). This suggests that there may be no difference in performance time between $R_iL_jA_kS_\ell$ and $R_jL_iA_kS_\ell$ under an ideal situation where there is no variation among subjects and the visual search strategies employed are consistent. The implication of the equal relationship will provide the ease of human

S	A	R	L	MEAN PT	DIFFER.	MAX. %	SIGNIFICANCE $P < 0.05$
2	45	6 3	3 6	420.91 442.47	21.56	4.87	S
		9 3	3 9	487.52 465.54	21.98	4.51	S
		12 3	3 12	532.47 518.83	13.64	2.56	NS
		9 6	6 9	509.98 533.96	23.98	4.49	S
		12 6	6 12	571.35 545.63	25.72	4.50	S
		12 9	9 12	606.39 603.24	3.15	0.52	NS
2	90	6 3	3 6	420.55 419.93	0.62	0.15	NS
		9 3	3 9	492.71 494.54	1.83	0.37	NS
		12 3	3 12	551.19 520.51	30.68	5.57	S
		9 6	6 9	466.79 491.55	24.76	5.04	S
		12 9	9 12	547.28 542.45	4.83	0.88	NS
		12 6	6 12	565.77 540.50	25.27	4.47	S

Table 3: $R_i\,L_j\,A_k\,S_l$ and $R_j\,L_i\,A_k\,S_l$ Comparison.

S	A	R	L	MEAN PT	DIFFER.	MAX. %	SIGNIFICANCE $P < 0.05$
10	45	6 3	3 6	474.53 498.11	23.58	4.73	S
		9 3	3 9	520.97 514.06	6.91	1.33	NS
		12 3	3 12	567.48 576.80	9.32	1.62	NS
		9 6	6 9	598.82 582.99	15.83	2.64	S
		12 6	6 12	602.88 620.50	17.62	2.84	S
		12 9	9 12	673.46 664.82	8.64	1.28	NS
10	90	6 3	3 6	466.88 459.47	7.41	1.59	NS
		9 3	3 9	529.41 516.25	13.16	2.49	NS
		12 3	3 12	578.61 570.06	8.55	1.48	NS
		9 6	6 9	528.87 552.03	23.16	4.20	S
		12 6	6 12	591.28 586.67	4.61	0.78	NS
		12 9	9 12	602.78 581.87	20.91	3.47	S

Table 3 continued

performance time prediction and the design of work layout.

8. Interaction Terms

The result of the ANOVA in Appendix C.2 indicates the interaction terms, namely R*L, R*A, R*L*A, R*L*A*HAND, L*A*HAND, A*S*HAND, L*HAND, are significant at $P<0.05$, but not significant at $P<0.01$. From Appendix C.0, Figures C3 and C4 the graphs show that R*L interaction effect occurs only at S=2" and A=90°. As discussed previously, visual effect at this level is minimum and SIMO performance time behaves differently as compared to the case where visual effect can no longer be neglected. As a result only limiting-hand effect is dominant. Also it is evident from the graphs that the performance times of those conditions under the same limiting-hand distance are very close and most of them are not significantly different from each other (as indicated by the circle on the curves). It is these close values which induce the R*L interaction effects. In the case of ideal situation where there is no subject variation, the interaction effect will vanish. Moreover the R*L interaction effect is small. This can also be confirmed by the calculation of component variance (Appendix C.2 (a)) that the variance contributed by R*L is only 3.70%.

The interactions of R*A, L*A are illustrated in

Appendix C.0, Figure C11 to C12, for both symmetrical and asymmetrical SIMO. From the graphs it can be seen in general that SIMO performance times at A=45° are greater than those at A=90° with the exception of few conditions which give rise to the interaction effects. These few exceptional conditions only occur when one hand travels at a distance of 3 inches and the other hand travels at a longer distance (>9"). In this case SIMO performance times are slightly higher at A=90° than at A=45°. This contradicts with the results of other conditions which both R and L are greater than 3". This result is not surprising because of:

(i) at A=90° visual effect is at a minimum;

(ii) when either R or L = 3" and other hand travels at a longer distance there is a great tendency that the subject's slavery hand will terminate the switch ahead of the limiting hand. Since one hand travels only at a very short distance of 3", the subject does not have to look at this distance after a few practice trials. As a result, the subject, though still performing SIMO, is acting like performing a 1-hand motion;

(iii) the greater PT time value is understandable because for 1-hand reach the performance time is higher at straight ahead position (A=90°) due to biomechanical effect (which refers to the muscle ease). Chapter 6 confirms this finding. More biomechanical effect will be discussed in Chapter 7.

Also when the difference of distance traveled between R and L is small as in the case of 3" by 6" or 3" by 3" the SIMO performance times are not significantly different from each other at A=45° and A=90°. This result also agrees with the 1-hand experiment in Chapter 6 where angle effect becomes significant <u>only</u> when distance traveled is more than 6". In short, when either one hand travels a distance ≤3" and the other hand travels >3", the subject, though still performing SIMO, is acting like performing a 1-hand motion. Since the angle effect upon performance time is reverse in the case of 1-hand motion (see Chapter 6), this explains the reverse pattern on the graphs (Figures C.11 and C.12), under the above conditions.

As for R*L*A, since there are interactions between R*L, R*A, and L*A, therefore this interaction term will follow.

The computation of component variance of the interaction terms (see Appendix C.2 (a)) indicates their total contribution to variance is 9.51%. And for the interaction terms with handedness the total variance contribution is 2.48%. The existence of handedness interaction terms is believed to have caused by the subject variance and the different visual search strategy employed by the subjects.

(b) Symmetrical SIMO

1. ANOVA

By considering only symmetrical simultaneous motions (SYM-SIMO) where R=L, a variable symbol B is used to denote the equal distances traveled by both hands. An EMS table was constructed (Appendix C.0, Table C4). Then the ANOVA was computed as shown in Appendix C.8. The results indicate that the performance time for symmetrical simultaneous motions (SYMPT) can be expressed as

SYMPT = f(B, A, S, B*A, B*A*HAND) for $P<0.05$

For $P<0.01$, above expression reduces to

SYMPT = f(B, A, S, B*A)

From the computation of component variance of the significant effects (Appendix C.9), it has been found that the variance contribution by B*A is 2.95% and B*A*HAND is only 0.81%. Also from Appendix C.0, Figure C11, B*A occurs only once at B=3". So it seems the SYMPT expression can best be represented by

SYMPT = f(B, A, S)

2. Regression Analysis

Appendix C.10 shows the multiple regression analysis in two parts, namely

Part A : SYMPT = f(B, A, S, B*A, B*A*HAND)

and

Part B : SYMPT = f(B, A, S)

The results are summarized here as follow:

Part A :

SYMPT = 165.248 + 133.675B + 11.930A + 61.729S - 17.322B*A - 6.642B*A*HAND

r^2 = 0.672446, Response mean = 507.605, significant level of fit = 0.0001

Standard deviation = 79.435   Total data = 4480

Part B :

SYMPT = 267.569 + 92.747B − 56.283A + 61.729S

r^2 = 0.649602, Response mean = 507.605, significant level of fit = 0.0001

Standard deviation = 82.140   Total data = 4480

Comparing the two expressions, the difference in multiple regression coefficient square (r^2) is 0.022844. In standard deviation the difference is 2.705 msec. Also using standard deviation as a percentage of the mean response gives

Part A : 79.435/507.605 = 0.1565 or 15.65%;

Part B : 82.140/507.605 = 0.1618 or 16.18%

and the difference between the two percentages is 0.5319%.

In summary of above, the elimination of B*A and B*A*HAND only reduces the fit of regression by 0.022844, reduces the precision of estimation by 2.705 msec and reduces the standard error of estimate by 0.5319% of the mean response. With a small sacrifice of fit in exchange for the simplicity of SYMPT expression and the ease of application, then the regression expression in Part B is more favourable.

3. Test of Means

Duncan's multiple range means test was employed to find the significance of the levels for each variable. A computer output is shown in Appendix C.11. The results indicate that B is significant at all levels and is proportional to SYMPT. SYMPT has a higher value at A=45° than those at 90° and it is also higher at S=10" than at S=2".

A test of significance of the means can be found in Appendix C.6 under the condition numbers 1, 6, 11, 16, 17, 22, 27, 32, 33, 38, 43, 48, 49, 54, 59 and 64. All the above conditions are significantly different from each other for $P<0.05$, except the following:

$$B_3A_{45}S_2 \longleftrightarrow B_3A_{90}S_2$$

$$B_3A_{45}S_{10} \longleftrightarrow B_3A_{90}S_{10}$$

$$\begin{tikzcd}
B_6A_{45}S_2 \arrow[r, leftrightarrow] \arrow[dr, leftrightarrow] & B_6A_{90}S_{10} \arrow[d, leftrightarrow] \\
 & B_9A_{90}S_2
\end{tikzcd}$$

$$\begin{tikzcd}
B_9A_{45}S_{10} \arrow[dr, leftrightarrow] & \\
 & B_{12}A_{90}S_{10}
\end{tikzcd}$$

$$\begin{tikzcd}
B_9A_{45}S_2 \arrow[d, leftrightarrow] \arrow[dr, leftrightarrow] & \\
B_9A_{90}S_{10} & B_{12}A_{90}S_2
\end{tikzcd}$$

Where the arrows indicate that the means between the conditions are not significantly different from each other. The above results indicate that angle effect (A) will not significantly affect the SYMPT when B≤3", as evident in the graph (see Appendix C, Figure C11). It also reveals that though at different levels of B, A, S, the performance times of SYM-SIMO may not be different from each other due to the compensation of time among the variable. For example, consider $B_6A_{45}S_2$ and $B_9A_{90}S_2$, the more time taken for hands to travel a longer distance (B=9") is compensated by the angle effect of less time required at A=90°. On the other hand for $B_6A_{45}S_2$ the effects of B and A are opposite to that in $B_9A_{90}S_2$. This explains the insignificant difference among some conditions.

5.6 Asymmetrical SIMO VS Symmetrical SIMO

This section will present a comparison between asymmetrical SIMO and symmetrical SIMO in respect to the main effects and mean performance times.

(a) Main Effects

The relationships of R, L, A, S in ASYM-SIMO and B, A, S in SYM-SIMO are illustrated graphically in Appendix C.0, Figures C11 to C14. Both the graphs and ANOVA exhibit the following similarities between the two:

1. All the main independent variables are significant for $P<0.05$.
2. When visual search effect is existed (that is $A\neq 90°$) and distances traveled by the hands are more than 3" both SYM-SIMO and ASYM-SIMO exhibit a similar pattern of response as main effect(s) varies. That is

   $PT \propto B, R, L, S$

   $PT \propto 1/A$ for $A=45°$ and $90°$.
3. Both indicate that there is very little difference in the performance times between $A=90°$ and $A=45°$ when performing SIMO with hands traveling at short distances (e.g. B = 3", R = 3", L = 6").
4. Both indicate that interaction terms do exist but only occur at a level where distances traveled by hands are short. Also their variance contributions are comparatively very small.

The significant difference between asymmetrical and symmetrical SIMO, as far as the independent variables are concerned, is the variance contribution. In symmetrical SIMO B alone accounts for 63.81% of the total variance while in asymmetrical SIMO the total variance will have to be distributed among more main effects and interaction terms. Hence symmetrical SIMO has a simpler response function than the asymmetrical one.

(b) Mean Performance Time

A comparison of the mean performance time is given in Appendix C.0, Table C5. The table shows the difference between SYM-SIMO performance time and the ASYM-SIMO performance time as R or L varies. And the followings are observed.

1. There is no indication that a constant may exist between ASYM- and SYM-SIMO, as R or L varies.
2. There is a strong indication that SYM-SIMO performance time is greater than ASYM-SIMO performance time under the condition that R and L are less than or equal to B and visual search is necessary i.e. $A \neq 90°$ and $S \neq 2"$.
3. When no visual search exists, SYM-SIMO performance time is close to ASYM-SIMO performance time whenever the distance traveled by the limiting hand equals the one in symmetrical SIMO.

5.7 Conclusions

From the results and analysis we can draw the following conclusions:

1. Handedness is not a significant factor affecting the performance time of SYM- or ASYM-SIMO ($P>0.05$).
2. The angle of reach (A), the starting separation distance (S) and the distances traveled by both hands are significant factor for both ASYM- and SYM-SIMO ($P<0.05$).
3. The prediction of SIMO performance times for both asymmetrical and symmetrical can be approximated by the multiple linear regression models outlined in section 5.5(a) and (b). Symmetrical SIMO regression model has a much simpler form than asymmetrical one due to the absence of interaction terms.
4. Visual effect is an important factor in analysing the performance time of simultaneous 2-hand reach motions. This confirms with the existing literature.
5. There is a great tendency of the subjects to use probabilistic visual search strategy when performing SYM-SIMO, but deterministic visual search strategy is often used when performing ASYM-SIMO especially when the difference of R and L is large. There is some evidence indicating that deterministic visual search is more efficient when performing asymmetrical SIMO,

so it seems it is advantageous to train the operators to use this strategy. Block (6) also found there was a slight increase in cycle time for those subjects who used a mixed eye movement pattern as opposed to the use of consistent eye movement pattern when performing symmetrical SIMO tasks.

6. The mean SIMO performance times of conditions R_i L_j A_k S_ℓ and R_j L_i A_k S_ℓ are close to each other, with a maximum difference of 30.68 msec or 5.57%, and in many cases they are not significantly different from each other (P>0.05). This indicates the reverse of distances traveled by right and left hand will not contribute a big difference in ASYM-SIMO performance time. Hence the application of this finding will make it easier for the prediction of ASYM-SIMO performance time and will facilitate the work layout as well.

7. To a certain extent SYM-SIMO performance time is greater than ASYM-SIMO performance time as long as the distance traveled by the limiting hand is shorter than or equal to the symmetrical one. This confirms with the findings of Raphael and Clapper (13). However we also found that in the case where visual search is minimum (at A=90°, S=2") both asymmetrical and symmetrical SIMO performance times are close to each other under the same limiting distance.

8. The limiting hand effect prevails in all asymmetrical SIMO. This confirms with the findings of Raphael and Clapper (13) that the ASYM-SIMO performance time should be determined by the limiting hand.

CHAPTER VI

STUDY #3 - SINGLE-HANDED REACH MOTIONS

6.1 Introduction

The objectives of this study were (1) to investigate how the same factors, which applied in simultaneous 2-hand reach motions, might affect preferred single-handed reach motions, (2) to compare single-handed reach motions with simultaneous 2-hand reach motions.

6.2 Experiment

(a) Experimental Conditions

The levels of the variables included in this experiment were as follow:

Variables	Level 1	Level 2	Level 3	Level 4
D	3"	6"	9"	12"
A	45°	90°		
S	1"	5"		
H	right	left		

where D = Distance traveled by preferred hand

A = Angle of reach with 90° representing straight ahead

S = Initial starting distance measured from the centre line of the SIMO equipment

H = Handedness of the subjects.

Appendix D.0, Table D1 reflects the levels of variables in ascending order of condition numbers, There was a total of 16 conditions per subject.

(b) Choice of Levels of D.A.S.

The levels were so chosen so that proper comparison with simultaneous 2-hand reach motion could be made. The variable S had the values 1" and 5" measuring from the center line of SIMO equipment, so that it could correspond to the same starting point as in the simultaneous reach motions experiment.

(c) Methodology

This study employed the same subjects who had performed the simultaneous reach motions experiment. Again the conditions were randomized and randomly assigned to each subject. Each condition's run was approximately 2 minutes, which allowed a collection of 40 to 70 data points. This experiment took about 1 1/2 hour to complete.

6.3 Data Analysis

The analysis model in this case is as follow:

$$PT_{jklmpn} = \mu + \sum^{\text{all}} D_j | S_k | A_l | H_m | O_{p(m)} + \varepsilon_{n(jklmp)}$$

where μ = constant

$\varepsilon_{n(jklmp)}$ = residual of cell repetition

$O_{p(m)}$ = subject nested with handiness, P = 1, 2, ..., 7

PT_{jklmpn} = performance time of n observation for j^{th} level of D, k^{th} level of S, l^{th} level of A, m^{th} level of H and p^{th} level of O.

The summation term is the sum of the combinations of all the main effects and interaction effects of the variables as defined before.

6.4 Experimental Results and Discussions

(a) Significant Variables

An EMS table (Appendix D.0, Table D2) was constructed to facilitate the ANOVA procedure. An ANOVA output computed by the SAS computer package is shown in Appendix D.1. A Duncan's multiple range test was used to find the level of significance of variables D, A, S (see Appendix D.3) and to test the significance of the overall means of 14 subjects for all conditions (Appendix D.4). Utilizing Duncan's multiple range test of means graphs were plotted as shown in Appendix D.0, Figures D1 to D3.

From the above results, the followings were observed:

1. From the ANOVA, handedness (H) of the subjects and all interaction terms are not significant ($P>0.05$),

therefore no further analysis on handiness is deemed to be necessary.

2. Distance traveled (D), angle (A), initial separation distance (S) and subjects (O) are found to be significant ($P<0.05$). S will become insignificant at a significant level of $\alpha = 0.01$.
3. From Duncan's tests of means, single-handed performance time (PT) increases as distance traveled (D) increases. Maximum PT occurs when initial separation distances (S) is equal to 10" and angle of reach (A) is at 90° and minimum when S=2" and A=45°.
4. From the graphs, at D=3", PT is not significantly affected by A and S and angle effect becomes more dominant only when D>6".

(b) Regression Analysis

Considering only the significant variables, the multiple regression equation of the performance time (PT) for single-handed reach motions was found to be

$PT = 164.13 + 59.77D + 25.31A + 9.06S$, $r^2 = 0.816556$ for $P<0.05$ and r is the coefficient of correlation (see Appendix D.5). The regression analysis also indicates that the parameter of S is not significant ($P>0.05$).

To test the sensitivity of S, another multiple regression of PT was performed <u>without</u> S (Appendix D.6) and the result was found to be

$$PT = 177.72 + 59.77D + 25.30A, \ r^2 = 0.812947$$

Comparing the r^2 in two PT expressions indicates that variable S is not highly significant as compared to D and A. This can also be confirmed from the graphs (Appendix D.0, Figure D2).

(c) Variance Components by Major Effects

Detailed computation of the variance components was presented in Appendix D.2. Results are summarized here

Component	% of variance
Subject Effect (O)	24.46
Distance Traveled (D)	71.45
Initial Separation Distance (S)	0.39
Angle of Movement (A)	3.70

Distance traveled (D) is the most significant effect in the model of this study. It accounts for about 3/4 of the total variance. Initial separation distance (S) and angle of reach (A) contribute a total of 4.1% of the total variance. This low contribution reflects, in accordance with the results obtained previously, that S is not significant at $P<0.01$ and angle of reach (A) becomes dominant only when $D>6"$.

6.5 Conclusions

From the above results and discussions, the following conclusions can be drawn.

1. Distance Effect (D) - It is the most significant effect in the model. Single-handed performance time is proportional to distance traveled (D).
2. Angle Effect (A) - Maximum single-handed performance time occurs at $A=90°$ and minimum at $A=45°$.
3. Initial Separation Effect (S) - Maximum single-handed performance time occurs at $S=5"$ and minimum at $S=1"$. Its effect becomes insignificant at $P<0.01$.
4. Handedness (H) - is not significant ($P>0.05$).
5. There is no interaction between variables.
6. Performance time (PT) can be expressed in the form

$$PT = 177.72 + 59.77D + 25.30A.$$

CHAPTER VII

GENERAL DISCUSSION AND COMPARISON

7.1 Introduction

This chapter will compare asymmetrical SIMO study with the single-handed study. A general discussion on the findings will be presented also.

7.2 Asymmetrical SIMO vs Single-Handed Reach Motions

(a) Independent Variables

1. Distance Effect

In both studies, distance(s) travels by the hand(s) is a significant variable, especially in single-handed study where "distance effect" outweighs all other main effects with a variance contribution of 71.45%. The ASYM-SIMO study indicates the distance effect, though significant, is having a comparatively smaller variance contribution (R+L=44.2%). The difference obviously is caused by the visual effect and balancing tendency effect which are existing in performing SIMO only. These effects, in turn, induce more variance contribution to other main effects and interaction terms. Balancing tendency is defined here as the hand travels at a shorter distance tends to slow down <u>or</u> the hand travels at a longer distance tends to speed up to match the 'pace' of the other hand. More balancing tendency will be discussed later.

2. Angle Effect

The response time behaves differently between SIMO and single-handed reach motions. In our asymmetrical SIMO study the performance time is greater at 45° angle than at 90°. Barnes and Mundel (3), Konz (9), Barnes and Balch (1) had also found that the SIMO performance time is minimum at 90°. The different SIMO response patterns at different angles and distances are believed to have caused by the visual effect and balancing tendency.

In the study of single-handed reach motions, the change in performance time due to the change of angle is reversed. It is greater at 90° than at 45° angle. It is believed that the biomechanical effect, or simply the ease of muscle response, is the sole explanation for this.

Comparing the impact of angle effect upon performance time in both studies, it is obvious that it has a greater effect on ASYM-SIMO due to the addition of visual search effect as opposed to the sole biomechanical effect in the single-handed reach motion case. This is also evident by the existence of interaction terms which are linked with the angle effect.

3. Initial Separation Distance Effect

Both studies exhibit similar response on performance time caused by the initial separation distance effect. However its impact on ASYM-SIMO is greater than that in single-handed reach motions. This is evident by the fact that its variance contribution in ASYM-SIMO study is 9.95% of the total variance as opposed to 0.39% in single-handed study. Again this can be explained by the existence of visual search effect because as the initial separation distance increases the target separation distance increases as well, hence the eyes will have to travel to a greater extent. The graphs in Appendix C.0, Figures C1 to C14 and Appendix D.0, Figure D1 to D3 also illustrate the difference of its impact in the two studies.

4. Mean Performance Time

Table 4 compares the mean performance times of ASYM-SIMO and single-handed reach motions. From the table, it indicates there is no single constant to relate ASYM-SIMO and single-handed reach motions as far as the overall performance times are concerned. The minimum percentage difference occurs at A=90°, S=2" with fairly constant average percentage ranged from 15.6% to 16.9% more than the single-handed performance time. Since no visual search is necessary at this level, therefore, the

ASYM - SIMO					1 - HAND			
				(a)		(b)	Difference	
S (in)	A (deg.)	L (in)	R (in)	Mean PT (ms)	D (in)	Mean PT (ms)	(a) - (b)	$(\frac{a-b}{a})$ %
2	45	3	3	336.69	3	263.66	73.03	21.70
			6	420.91	6	325.55	95.36	22.70
			9	487.52	9	377.56	109.96	22.60
			12	532.47	12	430.81	101.66	19.10
						% Average		21.53
		6	3	442.47	6	325.55	116.92	26.40
			6	475.31	6	325.55	149.75	31.50
			9	509.98	9	377.56	132.42	26.00
			12	571.35	12	430.81	140.54	24.60
						% Average		27.13
		9	3	465.54	9	377.56	87.98	18.90
			6	533.96	9	377.56	156.40	29.30
			9	566.01	9	377.56	188.45	33.30
			12	606.39	12	430.81	175.58	29.00
						% Average		27.60
		12	3	518.83	12	430.81	88.02	17.00
			6	545.63	12	430.81	114.82	21.00
			9	603.24	12	430.81	172.43	28.60
			12	652.37	12	430.81	221.56	34.00
						% Average		25.15

Note: Column (b) is the mean performance times (PT) which is corresponding to ASYM - SIMO's limiting distance travel.

Table 4: ASYM - SIMO and Single-Handed Mean PT Comparison.

ASYM - SIMO					1 - HAND			
				(a)		(b)	Difference	
S (in)	A (deg.)	L (in)	R (in)	Mean PT (ms)	D (in)	Mean PT (ms)	(a) - (b)	$(\frac{a-b}{a})$ %
2	90	3	3	326.49	3	273.65	52.84	16.2
			6	420.55	6	350.29	70.26	16.7
			9	492.71	9	406.64	86.07	17.5
			12	551.19	12	456.40	94.79	17.2
							Average	16.9
		6	3	419.93	6	350.29	69.64	16.6
			6	413.57	6	350.29	63.28	15.3
			9	466.79	9	406.64	60.15	12.9
			12	565.77	12	456.40	109.37	19.3
							Average	16.0
		9	3	494.54	9	406 64	87.9	17.8
			6	491.56	9	406.64	84.92	17.3
			9	484.18	9	406.64	77.54	16.0
			12	547.28	12	456.40	90.88	16.6
							Average	16.9
		12	3	520.51	12	456.40	64.11	12.3
			6	540.4	12	456.40	84.1	15.6
			9	542.45	12	456.40	86.05	15.9
			12	559.30	12	456.40	102.9	18.4
							Average	15.6

Table 4 continued

ASYM - SIMO					1 - HAND			
				(a)		(b)	Difference	
S (in)	A (deg.)	L (in)	R (in)	Mean PT (ms)	D (in)	Mean PT (ms)	(a) - (b)	$(\frac{a-b}{a})$ %
10	45	3	3	379.35	3	260.53	118.82	31.3
			6	474.53	6	339.98	134.55	28.4
			9	520.97	9	388.58	132.39	25.4
			12	567.48	12	432.93	134.55	23.7
						Average		27.2
		6	3	498.11	6	339.98	158.13	31.7
			6	535.65	6	339.98	195.67	36.5
			9	599.82	9	388.58	211.24	35.2
			12	602.88	12	432.93	169.95	28.2
						Average		32.9
		9	3	514.66	9	388.58	126.08	24.5
			6	582.99	9	388.58	194.41	33.3
			9	629.00	9	388.58	240.42	38.2
			12	673.46	12	432.93	240.53	35.7
						Average		32.9
		12	3	576.80	12	432.93	143.87	24.9
			6	620.50	12	432.93	187.57	30.2
			9	664.82	12	432.93	231.89	34.9
			12	711.58	12	432.93	278.65	39.2
						Average		32.3

Table 4 continued

ASYM - SIMO					1 - HAND			
				(a)		(b)	Difference	
S (in)	A (deg.)	L (in)	R (in)	Mean PT (ms)	D (in)	Mean PT (ms)	(a) - (b)	$(\frac{a-b}{a})$ %
10	90	3	3	382.21	3	273.94	108.27	28.3
			6	466.88	6	359.91	106.97	22.9
			9	529.41	9	427.48	101.93	19.3
			12	578.61	12	473.72	104.89	18.1
							Average	22.15
		6	3	459.47	6	359.91	99.56	21.7
			6	473.89	6	359.91	113.98	24.1
			9	528.87	9	427.48	101.39	19.2
			12	591.28	12	473.72	117.56	19.9
							Average	21.23
		9	3	516.25	9	427.48	88.77	17.2
			6	552.03	9	427.48	124.55	22.6
			9	577.3	9	427.48	149.82	26.0
			12	602.78	12	473.72	129.06	21.4
							Average	22.3
		12	3	570.05	12	473.72	96.33	16.9
			6	586.67	12	473.72	112.95	19.3
			9	581.87	12	473.72	108.15	18.6
			12	618.75	12	473.72	145.03	23.4
							Average	19.55

Table 4 continued

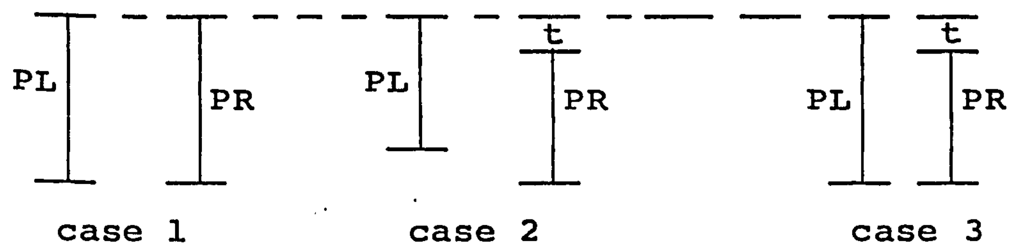
difference in performance time is believed to have been caused by the balancing tendency effect.

The maximum percentage difference occurs at A=45° and S=10". The table also indicates that when either A decreases or S increases the percentage difference increases as well. The increase is believed to have been caused by the increase of visual effect. Hence it leads to the conclusion that the increase of ASYM-SIMO mean performance time, as compared to single-handed study, is caused by the additional visual and balancing tendency effects.

(b) Determining Various Effects

1. Simultaneity Effect

Simultaneous 2-hand motions are defined as the motions of 2-hands start at the same time and complete the cycle at the same time. In practice this will not occur all the time. Very often there is a time difference (t) between the right-handed time (PR) and the left-handed time (PL) (see Figure 5). The question is how big the time difference should be so that the motions still can be considered as simultaneous motions. No conclusive answer has yet been given in the literature. However using the elemental time approach some guideline can be drawn to determine simultaneity. In our study we have found the simultaneous 2-hand reach motions have



t = time difference, PR = performance time of right hand
PL = performance time of left hand

Case 1: ideal SIMO

Case 2: PL started motion ahead of PR

Case 3: PL completed motion ahead of PR

Figure 5. Simultaneity Effect (Ref. #13)

greater performance times than the single-handed reach motions. Overall speaking there is no single constant to relate the two, but we have found the time difference is proportional to the visual effect as well as the balancing tendency effect. As a result, it is reasonable to suggest that the criteria for simultaneity is that the percentage in ASYM-SIMO performance-time-difference between the 2 hands should not exceed the percentage difference between the ASYM-SIMO and single-handed motions as found in Table 4.

In our study, the time difference between the right and left hand is shown in Appendix E.0 and the percentage difference is well below the limit of the difference between ASYM-SIMO and single-handed reach motions.

2. Biomechanical Effect

Biomechanical effect here refers to the effect of the 'ease of hand movements' due to physiological factors such as muscle contraction, the pivot point and weight of the arm, dexterity etc. In single-handed reach experiment, due to the absence of visual and balancing tendency effects, the main cause affecting subject's performance is the biomechanical effect. Since the results indicate that single-handed reach performance time is a function of D, A, S, let us define the followings

BM_D = biomechanical effect due to distance travels by hand

BM_A = biomechanical effect due to angle of hand movement

BM_S = biomechanical effect due to the initial separation distance

PT_{SH} = single-handed performance time

PT_{BH} = ASYM-SIMO performance time

VE = visual effect

BT = balancing tendency effect

Therefore the performance times for both single-handed and ASYM-SIMO experiments can be expressed in terms of various effects as follow:

$$PT_{SH} = f(BM_D, BM_A, BM_S)$$

and

$$PT_{BH} = f(VE, BT, BM_A, BM_D, BM_S)$$

The biomechanical effects due to different D, A, S in PT_{SH} are shown in Tables 5, 6, 7 respectively. The results indicate there is no significant difference among the mean performance times at different angles with D=3". However when D=6" or greater, the PT_{SH} difference becomes larger. This indicates that BM_D is more dominant when D is greater than 6 inches.

			(a)		(b)								
S (in)	A (deg.)	D (in)	Mean PT (ms)	D (in)	Mean PT (ms)	Difference (b - a)	S (in)	A (deg.)	D (in)	Mean PT (ms)	D (in)	Mean PT (ms)	Difference (b - a)
1	45	3	263.66	6	325.55	61.89	5	45	3	260.53	6	339.98	79.45
				9	377.56	113.9					9	388.58	128.05
				12	430.81	167.15					12	432.93	172.40
		6	325.55	9	377.56	52.01			6	339.98	9	388.58	48.60
				12	430.81	105.26					12	432.93	92.95
		9	377.56	12	430.81	53.25			9	388.58	12	432.93	44.35
1	90	3	273.65	6	350.29	76.64	5	90	3	273.94	6	359.91	85.97
				9	406.64	132.99					9	427.48	153.54
				12	456.40	182.75					12	472.72	198.78
		6	350.29	9	406.64	56.35			6	359.91	9	427.48	67.57
				12	456.40	106.11					12	472.72	112.81
		9	406.64	12	456.40	49.76			9	427.48	12	473.72	46.24

Table 5: Biomechanical Effect of 1-Hand Reach Motions at Different Distance (D).

			(a)		(b)	(b) - (a)	
S (in)	A (deg.)	D (in)	Mean PT (ms)	A (deg.)	Mean PT (ms)	Difference (ms)	$(\frac{b-a}{a})$ %
1	45	3	263.66	90	273.65	9.99	3.79
		6	325.55		350.29	24.74	7.60
		9	377.56		406.64	29.08	7.70
		12	430.81		456.40	25.59	5.94
5	45	3	260.53	90	273.94	13.41	5.15
		6	339.98		359.91	19.93	5.86
		9	388.58		427.48	38.90	10.01
		12	432.93		473.72	40.79	9.42

Table 6: **Biomechanical Effect of 1-Hand Reach Motion at Different Angle of Reach (A).**

			(a)		(b)	(b) - (a)	
S (in)	A (deg.)	D (in)	Mean PT (ms)	S (in)	Mean PT (ms)	Difference (ms)	$(\frac{b-a}{a})$ %
1	45	3	263.66	5	260.53	- 3.13	-1.20
		6	325.55		339.98	14.43	4.43
		9	377.56		388.58	11.02	2.92
		12	430.81		432.93	2.12	0.49
1	90	3	273.65	5	273.94	0.29	0.11
		6	350.29		359.91	9.62	2.75
		9	406.64		427.48	20.84	5.12
		12	456.40		473.72	17.32	3.79

Table 7: Biomechanical Effect of 1-Hand Reach Motion at Different Starting Separation Distance (S).

Comparing the three tables they also indicate that the biomechanical effect due to distance travel has the greatest impact upon performance time, while BM_S has the least.

3. Balancing Tendency Effect

Balancing tendency occurs in SIMO only. It refers to the situation where the hand traveling a shorter distance tends to slow down <u>or</u> the hand traveling a longer distance tends to speed up so as to match the 'pace' of the other hand. Very little information on this subject is available in the literature. Within the limitation of our experiment an attempt to determine the balancing tendency is made.

Since biomechanical effect is a measure of the ease of each hand movement at different D, A, S, from the physiological point of view we may assume there is no difference in biomechanical effects between SIMO and single-handed reach motions.

Let us consider only the case where there is no visual search required, that is, at A=90° and S=2". Since the biomechanical effects are assumed to be the same for both SIMO and single-handed reach motions, therefore the measure of balancing tendency effect is simply the performance time difference between the two studies. Table 4 used previously can be used here again. The results are entered in table 8. The difference of the two means becomes the measure of the balancing tendency effect. Since the results indicate that the percentages are very close to each other, therefore it leads to a strong belief that balancing tendency is a constant percentage of 16% in terms of the ASYM-SIMO mean performance times. This result is not surprising because the balancing tendency is a measure of the interaction or adjustment between the 2 hands in motion and should not be confused with biomechanical effect which measures mainly the arm muscle ease. Therefore the longer the 2 hands in motion the higher the balancing tendency effect.

4. Visual Search Effect

Visual search effect is the measure of the time taken by the eyes to search the terminal targets. In our experiment visual search is necessary when A=45° and/or S=2". Since ASYM-SIMO can be represented by

$$PT_{BH} = f(VE, BT, BM_D, BM_A, BM_S)$$

and all the biomechanical effects are assumed to be constant in both ASYM-SIMO and single-handed studies, hence by utilizing the results of the biomechanical effects in Tables 5, 6, 7 and the constant percentage in

ASYM - SIMO					1 - HAND			
				(a)		(b)	Difference	
S (in)	A (deg.)	L (in)	R (in)	Mean PT (ms)	D (in)	Mean PT (ms)	(a) - (b)	$(\frac{a-b}{a})$ %
2	90	3	3	326.49	3	273.65	52.84	16.2
			6	420.55	6	350.29	70.26	16.7
			9	492.71	9	406.64	86.07	17.5
			12	551.19	12	456.40	94.79	17.2
							Average	16.9
		6	3	419.93	6	350.29	69.64	16.6
			6	413.57	6	350.29	63.28	15.3
			9	466.79	9	406.64	60.15	12.9
			12	565.77	12	456.40	109.37	19.3
							Average	16.0
		9	3	494.54	9	406.64	87.9	17.8
			6	491.56	9	406.64	84.92	17.3
			9	484.18	9	406.64	77.54	16.0
			12	547.28	12	456.40	90.88	16.6
							Average	16.9
		12	3	520.51	12	456.40	64.11	12.3
			6	540.5	12	456.40	84.1	15.6
			9	542-45	12	456.40	86.05	15.9
			12	559.30	12	456.40	102.9	18.4
							Average	15.6

Table 8: Balancing Tendency Effect

balancing tendency the visual search effect can be determined.

(i) Single-hand Reach VS ASYM-SIMO Reach

For single-handed reach motions, let

$$PT_{SH} = f(BM_{D1}, BM_{A1}, BM_{S1}) \text{ .... } (1)$$

and, for ASYM-SIMO let

$$PT_2 = f(VE_2, BT_2, BM_{D2}, BM_{A2}, BM_{S2}) \text{ ...... } (2)$$

with the various effects defined as before.

VE_2 and BT_2 are missing in expression (1) because there is no visual search effect and balancing tendency effect in single-handed reach motions.

Substract (1) from (2), the relationship of visual effect (VE) in terms of mean performance times for both ASYM-SIMO and single-handed motions can be expressed as

$$VE_2 = (PT_2 - PT_{SH} - BT_2 - (BM_{D2} - BM_{D1}) - (BM_{A2} - BM_{A1}) - (BM_{S2} - BM_{S1}) \text{ .... } (3)$$

where $BT_2 = 0.16\ PT_2$ as found in Table 8. The difference between the biomechanical effect terms can be obtained from Tables 5, 6, 7. With PT_{SH} and PT_2 being known the visual effect can be determined.

Alternatively, expression (2) can be expressed in terms of PT_{SH}, that is

$$PT_2 = f(VE_2, BT_2, PT_{SH2})$$

therefore

$$VE_2 = PT_2 - PT_{SH2} - 0.16\ PT_2$$
$$= 0.84\ PT_2 - PT_{SH2} \qquad \ldots\ldots\ldots\ldots\ldots (4)$$

Expression (4) is useful in determining the magnitude of visual search effect in any ASYM-SIMO performance time provided that the single-handed performance time is also known.

(ii) Visual effect on SIMO

Let

$$PT_3 = f(VE_3, BT_3, BM_{D3}, BM_{A3}, BM_{S3}) \ldots\ldots (5)$$

be the expression for another ASYM-SIMO condition, then the change of visual search effect ΔVE_s due to different ASYM-SIMO condition becomes

$$\Delta VE_s = PT_2 - PT_3 - 0.16(PT_2 - PT_3) - (BM_{D2} - BM_{D3}) - (BM_{A2} - BM_{A3}) - (BM_{S2} - BM_{S3})$$
$$= 0.84(PT_2 - PT_3) - (BM_{D2} - BM_{D3}) - (BM_{A2} - BM_{A3}) - (BM_{S2} - BM_{S3}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Expression (6) can be used to compare the visual effects at various conditions. For example, consider A2=45°, A3=90°, and R, L = 3", S=2" are the same for both conditions, then from the results in Table 4 PT_2 = 336.69 msec, PT_3 = 326.49 msec. From Table 6, $(BM_{A2} - BM_{A3})$ = 263.66 - 273.65 = -9.9 msec.

$$\therefore \Delta VE_S = 0.84(336.69 - 326.49) - 0 - (-9.9) - 0$$
$$= 18.56 \text{ msec}$$

Again expression (6) can be expressed in terms of single-handed performance times which having the distances travel correspond to the limiting-hand distance of the ASYM-SIMO performance times. Then

$$\Delta VE_S = 0.84 \; (PT_2 - PT_3) - (PT_{SH2} - PT_{SH3}) \; \ldots \; (7)$$

where PT_{SH2} and PT_{SH3} are the single-handed reach performance times corresponding to PT_2 and PT_3 respectively.

Either expression (6) or expression (7) can be used to calculate the magnitude of change of visual search effect between two ASYM-SIMOs. Some results are shown in Table 9. The results indicate ΔVE increases as the angle of reach (A) changes from 90° to 45° and/or initial separation distance (S) changes from 2" to 10". There is no single constant found to relate this increase.

$$\Delta VE_s = 0.84\,(PT_2\text{-}PT_3) - (BM_{A2}\text{-}BM_{A3})$$

				(a)		(b)		
S (in)	A (deg)	L (in)	R (in)	Mean PT_2 (ms)	A (deg)	Mean PT_3 (ms)	(a)-(b)	ΔVE_s
2	45	3	3	336.69	90	326.49	10.20	18.56
			6	420.91		420.55	0.36	25.04
			9	487.52		492.71	- 5.19	24.72
			12	532.47		551.19	- 18.72	9.78
2	45	6	3	442.47	90	419.92	22.54	43.67
			6	475.31		413.57	61.74	76.60
			9	509.98		466.79	43.19	65.36
			12	571.35		565.77	5.58	30.28
2	45	9	3	465.54	90	494.54	- 29	4.72
			6	533.96		491.56	42.4	64.70
			9	566.01		484.18	81.83	97.82
			12	606.39		547.28	59.11	75.24
2	45	12	3	518.83	90	520.51	- 1.68	24.18
			6	545.63		540.50	5.13	29.90
			9	603.24		524.45	60.79	76.65
			12	652.37		559.30	93.07	103.77

Table 9: Determine the Visual Effect Difference Between Various ASYM-SIMO.

$\Delta VE_s = 0.84\,(PT_2 - PT_3) - (BM_{A2} - BM_{A3})$

				(a)		(b)		
S (in)	A (deg)	L (in)	R (in)	Mean PT_2 (ms)	A (deg)	Mean PT_3 (ms)	(a)-(b)	ΔVE_s
10	45	3	3	379.35	90	382.21	- 2.86	11.01
			6	474.53		466.88	7.65	26.36
			9	520.97		529.41	- 8.44	31.81
			12	567.48		578.61	- 11.13	31.44
10	45	6	3	498.11	90	459.47	38.64	52.39
			6	535.65		473.89	61.76	71.81
			9	599.82		528.87	70.95	98.50
			12	602.88		591.28	11.60	50.53
10	45	9	3	514.06	90	516.25	- 2.19	37.06
			6	582.99		552.03	30.96	64.91
			9	629.00		577.32	51.68	82.31
			12	673.46		602.78	70.66	100.14
10	45	12	3	576.80	90	570.05	6.75	46.46
			6	620.50		586.67	33.83	69.21
			9	664.82		581.87	82.95	110.47
			12	711.58		618.75	92.83	118.77

Table 9 continued

$\Delta VE_s = 0.84\,(PT_2 - PT_3) - (BM_{S2} - BM_{S3})$

S (in)	A (deg)	L (in)	R (in)	(a) Mean PT_2 (ms)	S (in)	(b) Mean PT_3 (ms)	(a)-(b)	ΔVE_s
10	45	3	3	379.35	2	336.69	42.66	32.70
			6	474.53		420.91	63.52	30.61
			9	520.97		487.52	33.45	39.12
			12	567.48		532.47	35.01	31.53
10	45	6	3	498.11	2	442.47	55.64	32.31
			6	535.65		475.32	60.33	36.25
			9	599.82		509.98	89.84	86.49
			12	602.88		571.35	31.53	28.61
10	45	9	3	514.06	2	465.54	48.52	51.78
			6	582.99		533.96	49.03	52.21
			9	629.00		566.01	62.99	63.93
			12	673.46		606.39	67.07	58.46
10	45	12	3	576.80	2	518.82	57.97	50.81
			6	620.50		545.63	74.87	65.01
			9	664.82		603.24	61.58	53.85
			12	711.58		652.37	59.21	51.86

Table 9: continued

$$\Delta VE_s = 0.84\,(PT_2\text{-}PT_3) - (BM_{S2} - BM_{S3})$$

				(a)		(b)		
S (in)	A (deg)	L (in)	R (in)	Mean PT_2 (ms)	S (in)	Mean PT_3 (ms)	(a)-(b)	ΔVE_s
10	90	3	3	382.21	2	326.49	55.72	47.09
			6	466.88		420.55	46.33	48.54
			9	529.41		492.71	36.70	41.85
			12	578.61		551.19	27.42	25.15
10	90	6	3	459.47	2	419.93	39.54	42.83
			6	473.89		413.57	60.32	60.29
			9	528.87		466.79	62.08	72.99
			12	591.28		565.77	25.51	38.75
10	90	9	3	516.25	2	494.54	21.71	39.08
			6	552.03		491.56	60.47	71.63
			9	577.32		484.18	93.14	99.08
			12	602.78		547.28	55.5	63.94
10	90	12	3	570.05	2	520.51	49.54	58.93
			6	586.67		540.50	46.17	56.10
			9	581.87		542.45	39.42	50.43
			12	618.75		559.30	59.45	67.26

Table 9: continued

7.3 Comment on the Findings

From our findings and analysis it has found that R, L, A, S are all significant variables in the study of ASYM-SIMO. In the past, the common practice employed by the researchers was using only one or two variables. However our finding has proven that studying one or two variables alone is not sufficient to explore the full picture of ASYM-SIMO.

Table 10 shows the predetermined time values of the three predetermined motion time (PMT) systems (Ref. 10). Compare Table 10 with Table 5, our single-handed experimental values are higher than the PMT values. This is due to the fact that our experimental reach motion consists of one extra motion, namely the motion of pressing the terminal bottom. Moreover, the PMT values do not take into consideration of the effects of angle of reach and starting separation distance. And yet our findings indicate these effects are also significant factors. In lieu of all these, the single-handed experimental values are still comparatively close to the PMT values.

However, when comparing PMT values with the experimental ASYM-SIMO values shown in Appendix C, Table C5, the SIMO values are far greater than the PMT values.

Distance	MTM	BMT	Work-factor
3"	190 ms	234 ms	192 ms
6"	252	282	282
9"	298.8	324	348
12"	345.6	360	390

Table 10: Predetermined Motion Time Values of PMT Systems

According to MTM and work factor system, no extra standard time is allowed when performing reach SIMO. And the time assigns to reach SIMO is the same as single-handed reach motions. Yet from our study we have found that there is a significant performance time difference between SIMO and single-handed reach motions. The magnitude of the difference ranged from 12.3% more than the single-handed to a maximum of 39.2% with an overall average of 23.52%, depended on the visual effect and balancing tendency effect. So there is a strong indication that ASYM-SIMO and single-handed reach motions should be treated separately in predicting their performance time.

According to BMT System, extra time is allowed when performing SIMO. The extra time is predetermined by two variables, namely the terminal separation distance and the tolerance of the targets. The allowance table (Ref. 10) is entered in Table 11.

Separation Distance	0	2	4	6	8	10	12	14	16	18	20	22	24
1/4" tolerance & over	0	10	18	27	34	41	47	54	59	65	69	74	78
1/8" ....".........	0	12	21	30	37	44	51	57	63	68	73	78	82
1/16" ......".........	0	15	27	37	45	53	61	68	75	80	86	91	96
1/32" ......".........	0	19	34	47	58	68	77	84	90	97	103	107	111

Table 11: BMT Table for Simultaneous Motions (Time in 1/10000 of a minute) Allowance

Comparing BMT's allowance table with our results in Table 4, at tolerance level greater 1/4", the extra times allowed at various terminal separation distance are much greater than what we had found, especially at large terminal separation distance. For example, from the BMT table at separation distance = 18", which corresponds to our experimental conditions of $R_6L_6A_{45}S_{10}$, $R_{12}L_9A_{45}S_2$ and $R_9L_{12}A_{45}S_2$, BMT allows 390 msec extra time for performing SIMO. However from Table 4 the differences in performance times between SIMO and single-handed reach motions for the above conditions were found to be 195.67, 175.58 and 172.43 milliseconds respectively. The discrepancy lies in the fact that (i) using terminal separation distance and tolerance as variables are not sufficient because some other combinations of the angle of reach, starting separation distance and distances travel by both hands can also generate the same terminal separation distance. And yet from our result it indicates that different angle of reach and different starting separation distance will also affect ASYM-SIMO performance time. (ii) The same table used for all the elemental motions such as move, transport, grasp etc. is not appropriate. For example the hands transporting heavy objects will tend to increase the performance time. Hence the balancing tendency effect will increase as well and the resulting performance time between SIMO and 1-hand will increase also.

Another approach of analysing SIMO is by looking at the various effects. Our analysis of breaking down the ASYM-SIMO performance time into 3 different effects, namely biomechanical, balancing tendency and visual search effect, has offered a better understanding on asymmetrical SIMO. Due to the lack of literatures in this subject, the measurement of these effects can not be confirmed. More investigations are necessary.

CHAPTER VIII

CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDY

In this thesis the various effects and the significant factors affecting the performance time of ASYM-SIMO and single-handed reach motions were investigated under laboratory conditions. The reach task was discrete in nature and repetitive. From the analysis of the experimental data collected, the following conclusions can be made with respect to such a task within the limitations of the experimental conditions.

1. There is no significant difference in performance times between right-handed and left-handed subjects upon performing asymmetrical or symmetrical single-handed reach motions ($P>0.05$).
2. The distances travel by hands, the angle of reach and the initial separation distance are all significant factors affecting SIMO performance time. Performance time increases as the distances travel and/or the starting separation distance increases, and decreases as the angle of reach changes from 45° to 90°.
3. The performance time of ASYM-SIMO is a function of visual search effect, balancing tendency effect and biomechanical effect, while for single-handed reach

motion the performance time is a function of biomechanical effect only.

4. The prediction of reach motions performance time for ASYM-SIMO, symmetrical SIMO and single-handed reach can be expressed in the form of regression models as shown in Chapter V and Chapter VI.
5. There is no single constant being found to relate the SIMO and single-handed reach motions except in the case where A=90° and S=2" and no visual search is necessary then there exists a constant of 16% more than the 1-hand mean performance time.
6. There is no single constant can be found to express the ASYM-SIMO performance time in terms of SYM-SIMO
7. Biomechanical effect due to distances travel has the greatest impact on reach motion performance time, and the initial separation distances has the least impact. The impact due to angle effect falls in between the above two variables.
8. Balancing tendency accounts for approximately 16% of the ASYM-SIMO performance time.
9. The magnitude of visual search effect varies according to the factors of distances travel, angles and initial separation distances. Its effect is proportional to the distances travel and the initial separation distances and inversely proportional to the angles of reach.

10. The fastest ASYM-SIMO performance time occurs when 2 target points are adjacent to each other in a straight ahead position.
11. When performing asymmetrical SIMO, the cycle time is governed by the limiting hand time.
12. The result indicates that deterministic visual search strategy is more efficient than probabilistic visual search strategy when performing ASYM-SIMO. So it seems it is advantageous to train the operators to use a fixed visual search strategy.
13. There is a strong indication that the performance time of $R_i L_j A_k S_\ell$ are not different from $R_j L_i A_k S_\ell$. The implication of this result means that prediction of ASYM-SIMO performance time and the work layout design can be made easier.

Suggestions for Further Studies:

1. Verification of the prediction models proposed is needed by further studies before it can be applied to determine standard performance time of similar industrial tasks.
2. The measurements of biomechanical effects, balancing tendency effect and visual effects needs further verification.

3. The efficiency of deterministic visual search and probabilistic visual search needs further investigation.
4. In the present study the terminal targets are fixed. The case where the terminal targets occurs in a probabilistic fashion has not yet been studied.

APPENDIX A.O

EQUIPMENT SET-UP

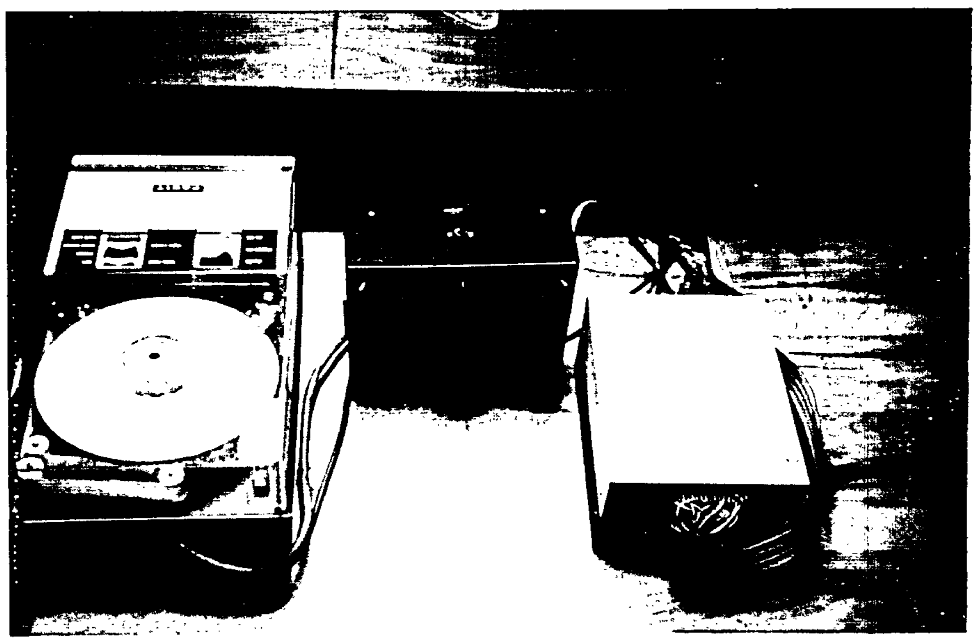
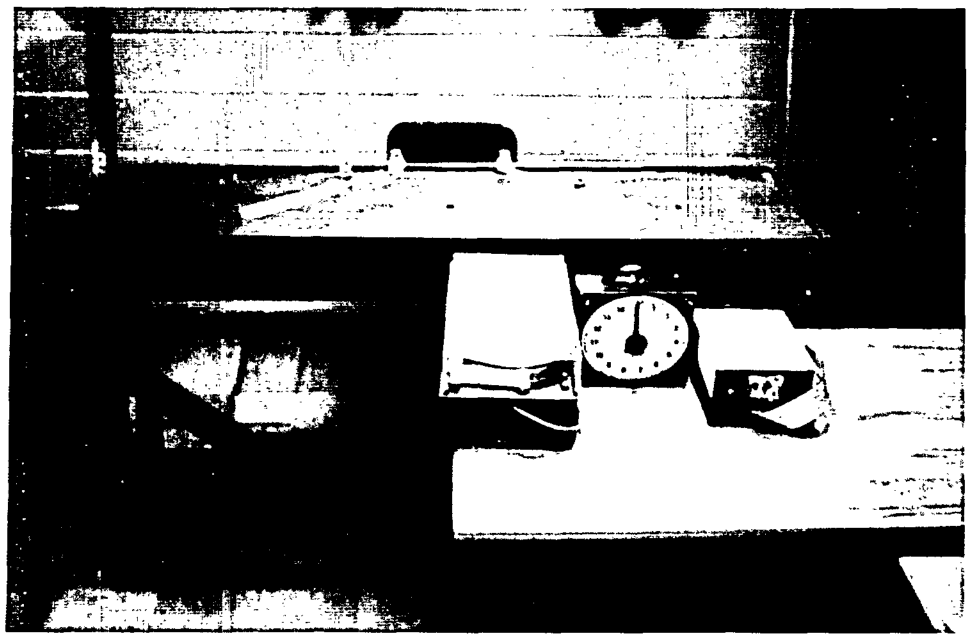


Figure A1 : Experimental Equipment Set-up



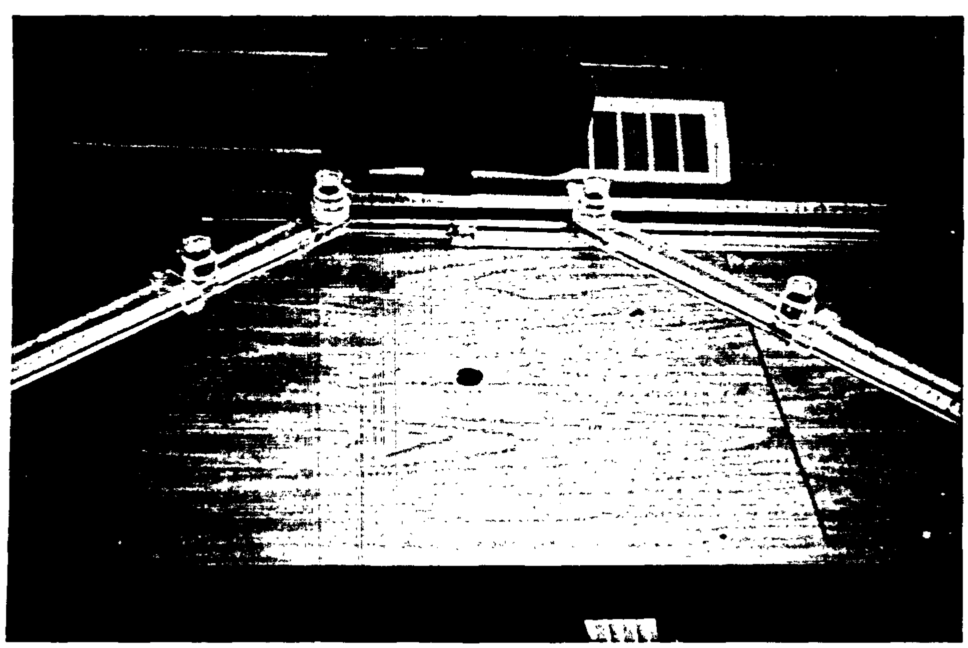


Figure A2: Close-up View on Equipment Units

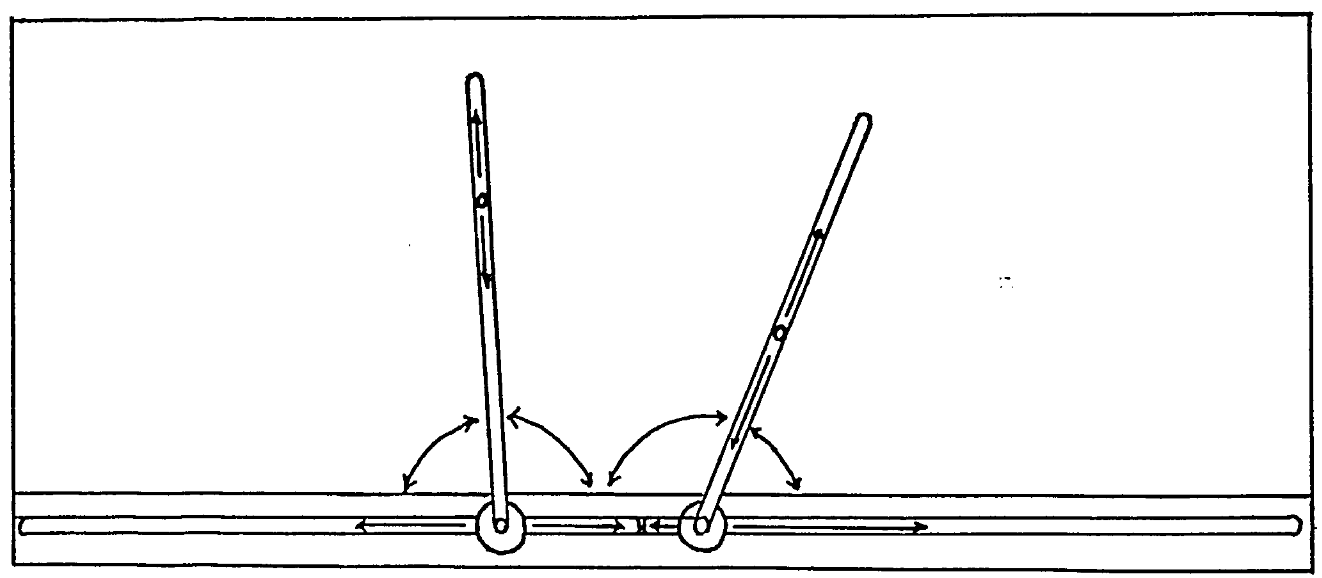


Figure A3 : Direction of Movement (Arrow)
for SIMO Unit

APPENDIX B.0
STUDY #1 - ASYM-SIMO LEARNING

Condition Number	Experimental Condition R	L	A	S	Sequence of experiment per subject 1	2	3	4	5
1	3	3	30	2	21	59	2	44	30
2	9				49	8	15	19	29
3	9	9			26	3	47	13	26
4	3				18	25	57	25	40
5	3	3	45		28	9	38	41	46
6	9				32	55	14	36	22
7	9	9			56	52	1	9	42
8	3				35	45	37	6	52
9	3	3	60		39	48	40	12	7
10	9				14	37	53	23	34
11	9	9			44	49	7	28	13
12	3				48	15	59	8	41
13	3	3	75		7	36	17	24	3
14	9				27	31	13	15	53
15	9	9			3	27	39	60	48
16	3				19	11	60	59	10
17	3	3	90		10	12	25	55	57
18	9				4	22	8	43	5
19	9	9			54	33	29	51	33
20	3				46	54	21	53	47

Table B1 : Experimental Conditions and Sequence of Performance - Study #1

Condition Number	Experimental Condition R	L	A	S	Sequence of experiment per subject 1	2	3	4	5
21	3	3	30	6	42	1	54	54	4
22	9				43	35	32	46	37
23	9	9			11	18	11	16	45
24	3				45	29	5	45	55
25	3	3	45		40	17	49	26	43
26	9				59	58	26	29	54
27	9	9			58	20	6	40	51
28	3				33	16	28	10	15
29	3	3	60		60	24	24	3	21
30	9				20	53	19	31	12
31	9	9			31	41	20	42	58
32	3				50	42	18	32	16
33	3	3	75		8	47	3	21	11
34	9				52	21	58	27	36
35	9	9			9	43	43	17	31
36	3				30	44	34	33	9
37	3	3	90		29	26	30	47	24
38	9				12	40	22	48	35
39	9	9			57	13	56	2	60
40	3				13	39	31	14	38

Table B1 continued

Condition Number	Experimental Condition				Sequence of experiment per subject				
	R	L	A	S	1	2	3	4	5
41	3	3	30	10	36	34	12	11	19
42	9				22	60	23	30	56
43	9	9			17	50	27	39	32
44	3				24	56	10	35	17
45	3	3	45		37	10	50	5	28
46	9				34	57	16	34	44
47	9	9			55	46	36	4	2
48	3				15	2	51	52	8
49	3	3	60		53	7	52	56	49
50	9				41	28	45	18	59
51	9	9			2	14	33	22	23
52	3				1	30	4	57	27
53	3	3	75		51	51	44	20	18
54	9				16	6	35	1	50
55	9	9			47	5	9	58	6
56	3				6	23	41	7	1
57	3	3	90		23	19	42	49	14
58	9				5	32	55	38	39
59	9	9			25	4	48	50	25
60	3				38	38	46	37	20

Table B1 continued

Subject Number	Condition Number									
	1	2	3	4	5	6	7	8	9	10
1 *	40	20	-0	0	0	20	-0	0	40	20
**	L	0	-L	0	0	L	0	0	L	L
2	0	20	20	0	40	0	0	20	40	0
	0	0	0	0	0	0	0	0	0	0
3	20	40	20	0	20	20	60	40	0	-0
	0	0	0	0	0	0	L	L	0	-L
4	-0	0	0	40	-0	40	20	0	60	60
	0	0	0	0	-L	0	0	0	0	0
5	20	40	0	40	60	60	40	0	20	60
	0	0	0	L	L	L	0	-0	0	L

	Condition Number									
	11	12	13	14	15	16	17	18	19	20
1	60	20	20	-0	20	40	60	20	0	20
	L	L	0	0	0	0	L	0	0	0
2	0	-0	20	20	20	0	0	20	20	20
	0	0	0	0	0	0	0	0	L	0
3	40	60	20	60	60	-0	0	20	0	20
	L	L	L	0	0	0	0	0	0	L
4	0	60	-0	20	-0	0	80	60	0	0
	0	L	-L	L	0	0	0	L	0	0
5	-0	60	20	-0	-0	60	-0	-0	-0	0
	0	0	0	-L	-L	0	-L	0	0	0

Table B2 : ASYM-SIMO Learning Table - Study #1

* Learning cycles obtained from Appendix B.6
** L=learning exists; O=no learning;
-L or -O = negative learning (see Appendix B.5)

Subject Number	Condition Number									
	21	22	23	24	25	26	27	28	29	30
1	40	-0	40	0	40	-0	0	20	0	0
	L	0	L	0	L	0	L	0	0	-L
2	20	20	-0	20	40	-0	40	0	-0	0
	0	0	-L	0	L	-L	L	0	-L	0
3	0	0	0	40	20	80	40	20	60	20
	0	0	0	0	0	0	0	L	L	0
4	0	0	0	0	20	0	0	0	0	20
	0	0	L	0	0	0	0	0	L	-L
5	40	0	0	20	-0	20	0	0	20	20
	-L	-L	0	L	-L	0	0	0	L	-L
	Condition Number									
	31	32	33	34	35	36	37	38	39	40
1	-0	0	40	-0	40	60	40	40	-0	20
	-L	0	0	-L	L	L	L	L	0	0
2	0	0	0	40	20	0	0	-0	0	-0
	0	0	0	0	-L	0	0	0	0	0
3	40	0	40	60	0	40	-0	-0	0	0
	0	0	L	0	0	L	-L	0	0	0
4	40	20	0	80	0	20	0	60	0	20
	L	0	0	0	0	0	L	L	0	0
5	-0	-0	20	20	0	40	20	80	0	0
	-L	-L	0	0	0	L	0	L	0	0

Table B2 continued

Subject Number	Condition Number									
	41	42	43	44	45	46	47	48	49	50
1	20	-0	20	20	20	0	0	60	0	0
	0	0	0	0	L	0	0	L	0	0
2	0	-0	0	0	20	80	-0	0	0	20
	-L	-L	0	0	0	0	0	0	0	0
3	20	40	0	60	0	20	0	0	60	0
	L	L	0	0	0	0	0	0	L	0
4	20	0	-0	0	0	0	0	0	40	0
	0	0	0	0	L	0	0	0	L	0
5	40	-0	0	0	40	40	20	20	40	60
	L	-L	0	0	L	L	0	0	0	0
	Condition Number									
	51	52	53	54	55	56	57	58	59	60
1	0	20	0	60	-0	0	0	20	20	-0
	0	L	0	L	-0	0	L	0	L	-L
2	0	0	40	40	-0	20	20	0	20	0
	0	0	L	L	0	L	L	0	L	0
3	0	20	20	20	0	-0	0	-0	0	20
	0	L	L	0	0	-L	0	0	0	L
4	0	0	20	0	0	0	-0	20	0	-0
	0	0	0	0	0	0	0	0	0	0
5	40	20	40	80	0	20	20	40	20	0
	L	0	0	L	0	0	0	0	0	0

Table B2 continued

Experimental design model: randomized mixed-factorial design

Main Effects	Symbol	Level	Type
Distance traveled by right hand	R_i	2	Fixed
Distance traveled by left hand	L_j	2	Fixed
Starting separation distance	S_k	3	Fixed
Angle of reach	A_l	5	Fixed
Subject	O_p	5	Random
Residual	$E_{n(ijklp)}$	20	Random

Table B3: EMS Table - Study #1

$$EMS = a\,\sigma_e^2 + b\,\sigma_x^2 + c\,\phi_y$$

Source	R	L	S	A	O	R_n	a	b	x	c	y
R_i	0	2	3	5	5	20	1	3000	RO	600	R
L_j	2	0	3	5	5	20	1	3000	LO	600	L
S_k	2	2	0	5	5	20	1	2000	SO	400	S
A_l	2	2	3	0	5	20	1	1200	AO	240	A
O_p	2	2	3	5	1	20	1	1200	O		
$(R*L)_{ij}$	0	0	3	5	5	20	1	1500	RLO	300	RL
$(R*S)_{ik}$	0	2	0	5	5	20	1	1000	RSO	200	RS
$(R*A)_{il}$	0	2	3	0	5	20	1	600	RAO	120	RA
$(R*O)_{ip}$	0	2	3	5	1	20	1	600	RO		
$(L*S)_{jk}$	2	0	0	5	5	20	1	1000	LSO	200	LS
$(L*A)_{jl}$	2	0	3	0	5	20	1	600	LAO	120	LA
$(L*O)_{jp}$	2	0	3	5	1	20	1	600	LO		
$(S*A)_{kl}$	2	2	0	0	5	20	1	400	SAO	80	SA
$(S*O)_{kp}$	2	2	0	5	1	20	1	400	SO		
$(A*O)_{lp}$	2	2	3	0	1	20	1	240	AO		
$(R*L*A)_{ijl}$	0	0	3	0	5	20	1	300	RLAO	60	RLA
$(R*L*O)_{ijp}$	0	0	3	5	1	20	1	300	RLO		

Table B3 continued

$$EMS = a\sigma_e^2 + b\sigma_x^2 + c\phi_y$$

Source	R	L	S	A	O	R_n	a	b	x	c	y
$(R*S*A)_{ikl}$	0	2	0	0	5	20	1	200	RSAO	40	RSA
$(R*S*O)_{ikp}$	0	2	0	5	1	20	1	200	RSO		
$(R*A*O)_{ilp}$	0	2	3	0	1	20	1	120	RAO		
$(R*L*S)_{ijk}$	0	0	0	5	5	20	1	500	RLSO	100	RLS
$(L*S*A)_{jkl}$	2	0	0	0	5	20	1	200	LSAO	40	LSA
$(L*S*O)_{jkp}$	2	0	0	5	1	20	1	200	LSO		
$(L*A*O)_{jip}$	2	0	3	0	1	20	1	120	LAO		
$(S*A*O)_{kpl}$	2	2	0	0	1	20	1	80	SAO		
$(R*L*S*A)_{ijkl}$	0	0	0	0	5	20	1	100	RLSAO	20	RLSA
$(R*L*S*O)_{ijkp}$	0	0	0	5	1	20	1	100	RLSO		
$(R*S*A*O)_{iklp}$	0	2	0	0	1	20	1	40	RSAO		
$(L*S*A*O)_{jklp}$	2	0	0	0	1	20	1	40	LSAO		
$(R*L*A*O)_{ijlp}$	0	0	3	0	1	20	1	60	RLAO		
$(R*L*A*S*O)_{ijklp}$	0	0	0	0	1	20	1	20	RLAS		
$E_{n(ijklp)}$	1	1	1	1	1	1	1				

Table B3 continued

APPENDIX B.1

COMPUTER PROGRAM FOR DATA INPUT - STUDY #1

```
S T A T I S T I C A L   A N A L Y S I S   S Y S T E M          14:05 SATURDAY, JULY 15, 1978
NOTE: THE JOB MAK HAS BEEN RUN UNDER RELEASE 76.6B OF SAS AT THE UNIVERSITY OF WINDSOR.

                DATA MAIN;
        LOOP1:  INPUT H 74 SUBJ 75-76 COND 77-80 @;
                RETAIN HAND CONDNO SUBJNO;
                IF H=. THEN GO TO LOOP2;
                NOOBS=1;
                HAND=H;
                CONDNO=COND;
                SUBJNO=SUBJ;
                INPUT / (P1-P18) (@2 18*4.);
                GO TO LOOP3;
        LOOP2:  INPUT (P1-P18) (@2 18*4.) ;
        LOOP3:  DROP P1-P18;
                IF P1=0 OR P2=0 THEN GO TO LOOP4;
                IF P1=. OR P2=. THEN DELETE;
                PR=P1*3; PL=P2*3; PT=MAX(PR,PL); OUTPUT;
                NOOBS=NOOBS+1;
        LOOP4:  IF P3=0 OR P4=0 THEN GO TO LOOP5;
                IF P3=. OR P4=. THEN DELETE;
                PR=P3*3; PL=P4*3; PT=MAX(PR,PL); OUTPUT;
                NOOBS=NOOBS+1;
        LOOP5:  IF P5=0 OR P6=0 THEN GO TO LOOP6;
                IF P5=. OR P6=. THEN DELETE;
                PR=P5*3; PL=P6*3; PT=MAX(PR,PL); OUTPUT;
                NOOBS=NOOBS+1;
        LOOP6:  IF P7=0 OR P8=0 THEN GO TO LOOP7;
                IF P7=. OR P8=. THEN DELETE;
                PR=P7*3; PL=P8*3; PT=MAX(PR,PL); OUTPUT;
                NOOBS=NOOBS+1;
        LOOP7:  IF P9=0 OR P10=0 THEN GO TO LOOP8;
                IF P9=. OR P10 =. THEN DELETE;
                PR=P9*3; PL=P10*3; PT=MAX(PR,PL); OUTPUT;
                NOOBS=NOOBS+1;
        LOOP8:  IF P11=0 OR P12=0 THEN GO TO LOOP9;
                IF P11=. OR P12=. THEN DELETE;
                 PR=P11*3; PL=P12*3; PT=MAX(PR,PL); OUTPUT;
                NOOBS=NOOBS+1;
        LOOP9:  IF P13=0 OR P14=0 THEN GO TO LOOP10;
                IF P13=. OR P14=. THEN DELETE;
                 PR=P13*3; PL=P14*3; PT=MAX(PR,PL); OUTPUT;
                NOOBS=NOOBS+1;
        LOOP10: IF P15=0 OR P16=0 THEN GO TO LOOP11;
                IF P15=. OR P16=. THEN DELETE;
                 PR=P15*3; PL=P16*3; PT=MAX(PR,PL); OUTPUT;
                NOOBS=NOOBS+1;
        LOOP11: IF P17=0 OR P18=0 THEN GO TO LOOP1;
                IF P17=. OR P18=. THEN DELETE;
                 PR=P17*3; PL=P18*3; PT=MAX(PR,PL); OUTPUT;
                NOOBS=NOOBS+1;
                KEEP HAND CONDNO SUBJNO PR PL NOOBS PT;
                GO TO LOOP1;
                CARDS;

NOTE: DATA SET WORK.MAIN HAS 27257 OBSERVATIONS AND 7 VARIABLES. 121 OBS/TRK.
NOTE: THE DATA STATEMENT USED 31.39 SECONDS AND 102K.

                PROC SORT; BY SUBJNO CONDNO;

NOTE: DATA SET WORK.MAIN HAS 27257 OBSERVATIONS AND 7 VARIABLES. 121 OBS/TRK.
NOTE: THE PROCEDURE SORT USED 32.34 SECONDS AND 106K.

                PROC MEANS DATA=MAIN NOPRINT;
                VAR PT; BY SUBJNO CONDNO;
                OUTPUT OUT=STATS MEAN=M STD=STANDEV;

NOTE: DATA SET WORK.STATS HAS 300 OBSERVATIONS AND 4 VARIABLES. 202 OBS/TRK.
NOTE: THE PROCEDURE MEANS USED 17.38 SECONDS AND 116K.

                DATA LEARNP;
                MERGE MAIN STATS;
                BY SUBJNO CONDNO;
                RETAIN OBS 1;
```

```
3527          ERORPT=2*STANDEV+M;
3528          LERORPT=M-4*STANDEV;
3529          IF FIRST.CONDNO=0 AND LAST.CONDNO=1 AND PT>ERORPT THEN GO TO L1;
3530          IF FIRST.CONDNO=0 AND LAST.CONDNO=1 AND PT<LERORPT THEN GO TO L1;
3531          IF PT<LERORPT THEN DELETE;
3532          IF PT>ERORPT THEN DELETE;
3533          OBS=OBS; OUTPUT;
3534          IF FIRST.CONDNO=0 AND LAST.CONDNO=1 THEN GO TO L1;
3535          OBS=OBS+1;
3536          RETURN;
3537     L1:  OBS=1;
3538          IF PT>ERORPT THEN DELETE;
3539          IF PT<LERORPT THEN DELETE;
3540          RETURN;
3541

NOTE: DATA SET WORK.LEARNP HAS 26137 OBSERVATIONS AND 12 VARIABLES. 72 OBS/TRK.
NOTE: THE DATA STATEMENT USED 49.78 SECONDS AND 104K.

3541          DATA REGR;
3542          SET LEARNP; BY SUBJNO CONDNO;
3543          RETAIN TPT 0 MN 0;
3544          RETAIN FOBS 0;
3545          TPT=TPT+PT;
3546          MN=MN+1;
3547          IF FIRST.CONDNO=0 AND LAST.CONDNO=1 THEN GO TO L1;
3548          IF MN<5 THEN RETURN;
3549     L1:  MEANPT=TPT/MN; FOBS=FOBS+1; OUTPUT;
3550          TPT=0; MN=0; FOBS=0; RETURN;
3551

NOTE: DATA SET WORK.REGP HAS 5347 OBSERVATIONS AND 16 VARIABLES. 55 OBS/TRK.
NOTE: THE DATA STATEMENT USED 19.13 SECONDS AND 104K.

3551          PROC GLM;  BY SUBJNO CONDNO;
3552          MODEL MEANPT=FOBS / P CLM;
3553          TITLE MULTIPLE REGRESSION FOR LEARNING;

NOTE: THE PROCEDURE GLM USED 168.73 SECONDS AND 154K AND PRINTED PAGES 1 TO 300.

NOTE: SAS USED 154K MEMORY.

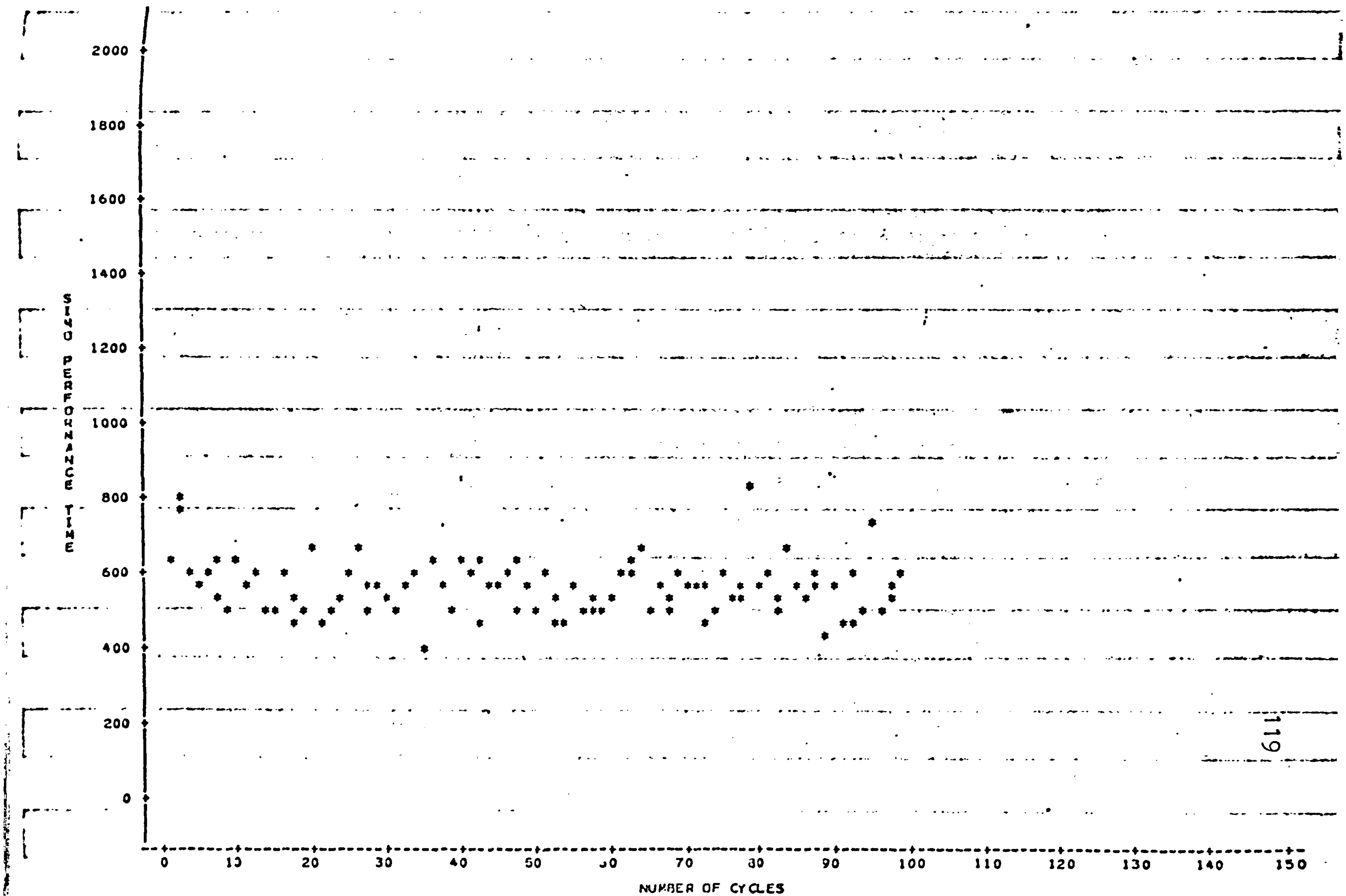
NOTE: BARR, GOODNIGHT, SALL AND HELWIG
      SAS INSTITUTE INC.
      P.O. BOX 10066
      RALEIGH, N.C. 27605
```

APPENDIX B.2

OVERALL LEARNING CURVES - STUDY #1

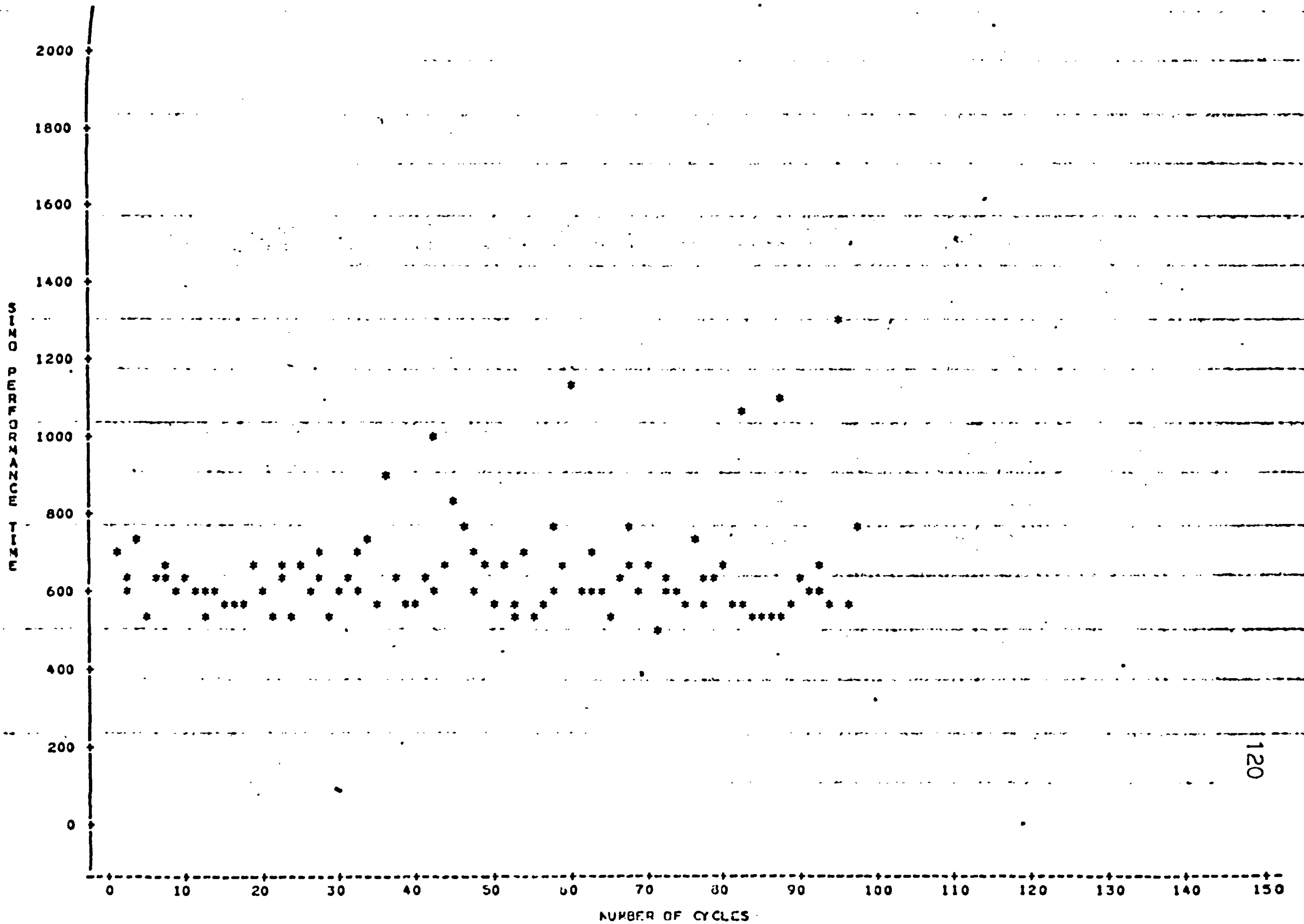
STUDY 1 LEARNING EFFECT 18:42 SUNDAY, JULY 9, 1978 46
SUBJNC=1 CONDNJ=16

PLOT OF PT*NOOBS SYMBOL USED IS *



STUDY 1 LEARNING EFFECT
SUBJNO=2 CONDNJ=46

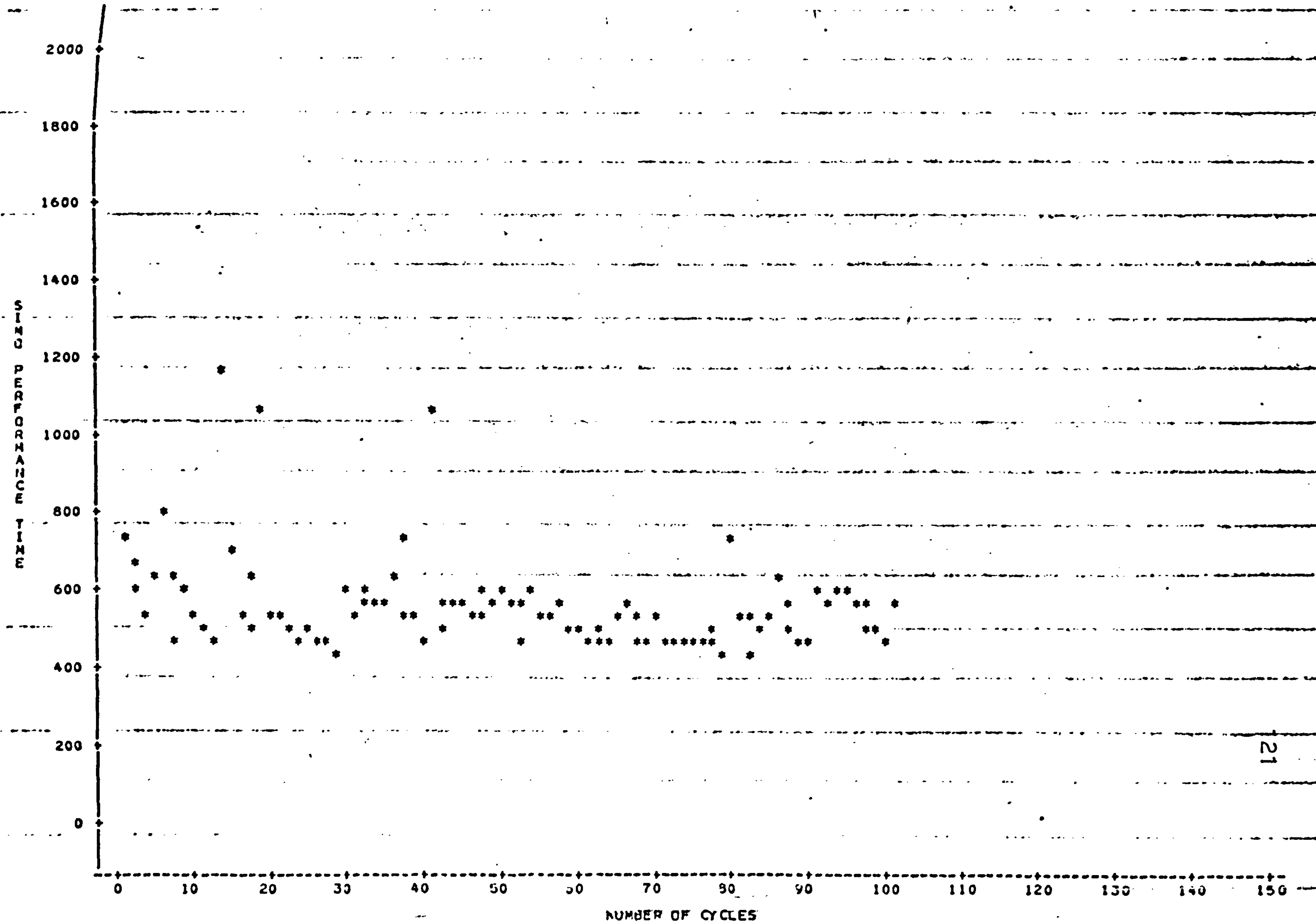
PLOT OF PT*NOOBS SYMBOL USED IS *



NOTE: 2 OBS HIDDEN

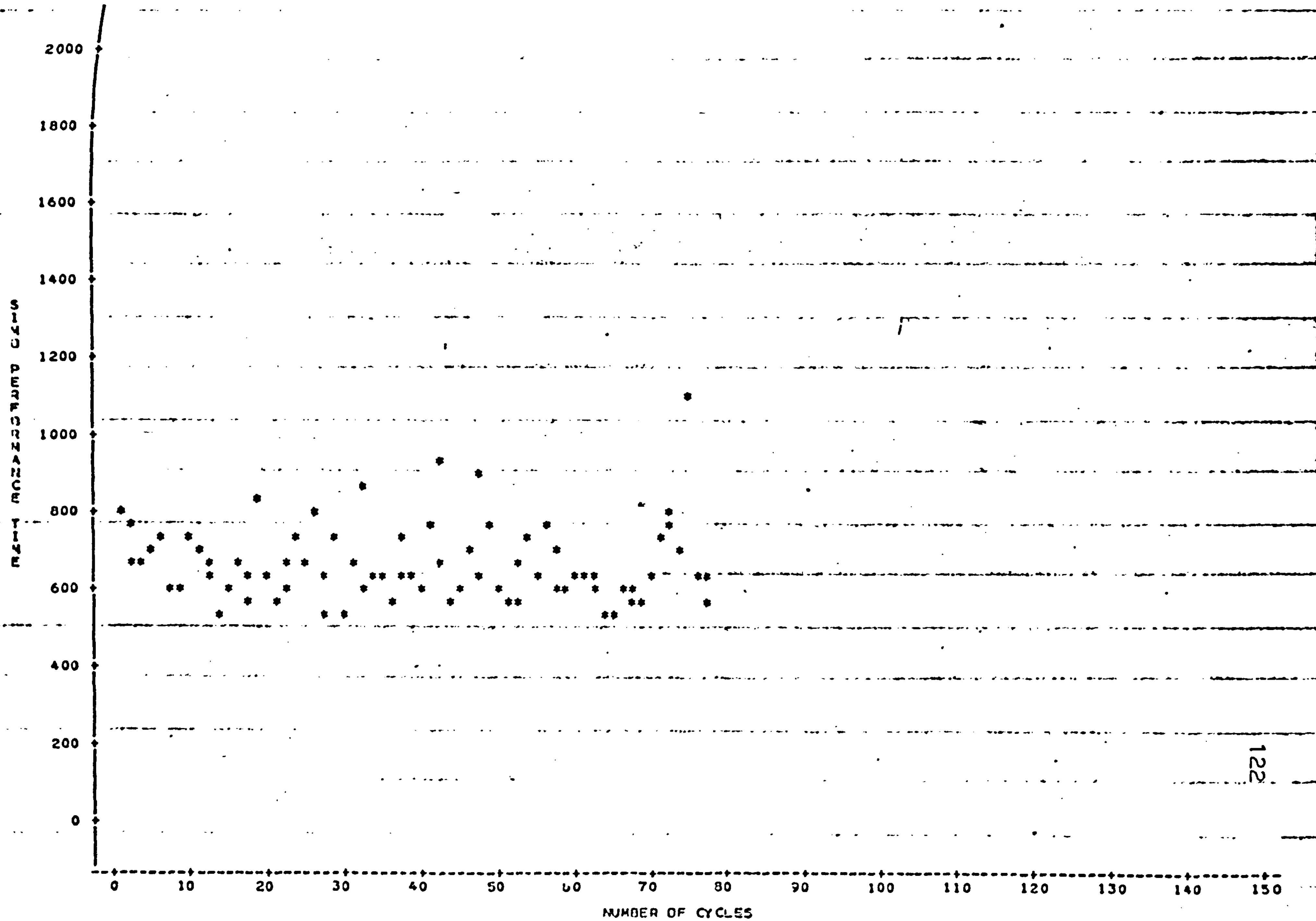
STUDY 1 LEARNING EFFECT 18:42 SUNDAY, JULY 9, 1978 166
SUBJNO=3 CONDNO=16

PLOT OF PT*NOOBS SYMBOL USED IS *



STUDY 1 LEARNING EFFECT
SUBJNO=4 CONDNO=46

PLOT OF PT*NOOBS SYMBOL USED IS *

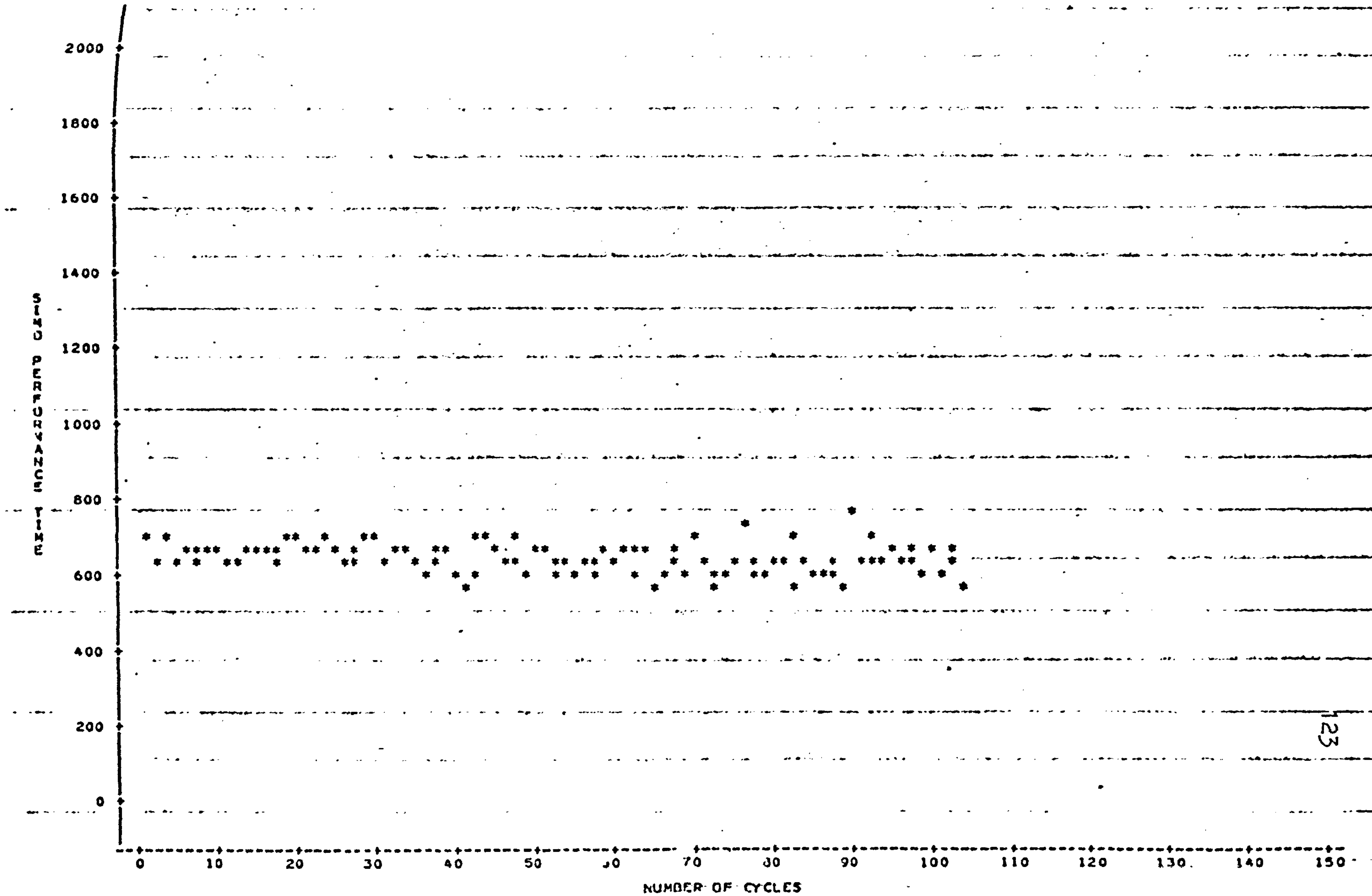


NOTE: 1 OBS HIDDEN

STUDY 1 LEARNING EFFECT
SUBJNO=5 CONDNJ=46

18:42 SUNDAY, JULY 9, 1978 286

PLOT OF PT*NOOBS SYMBOL USED IS *

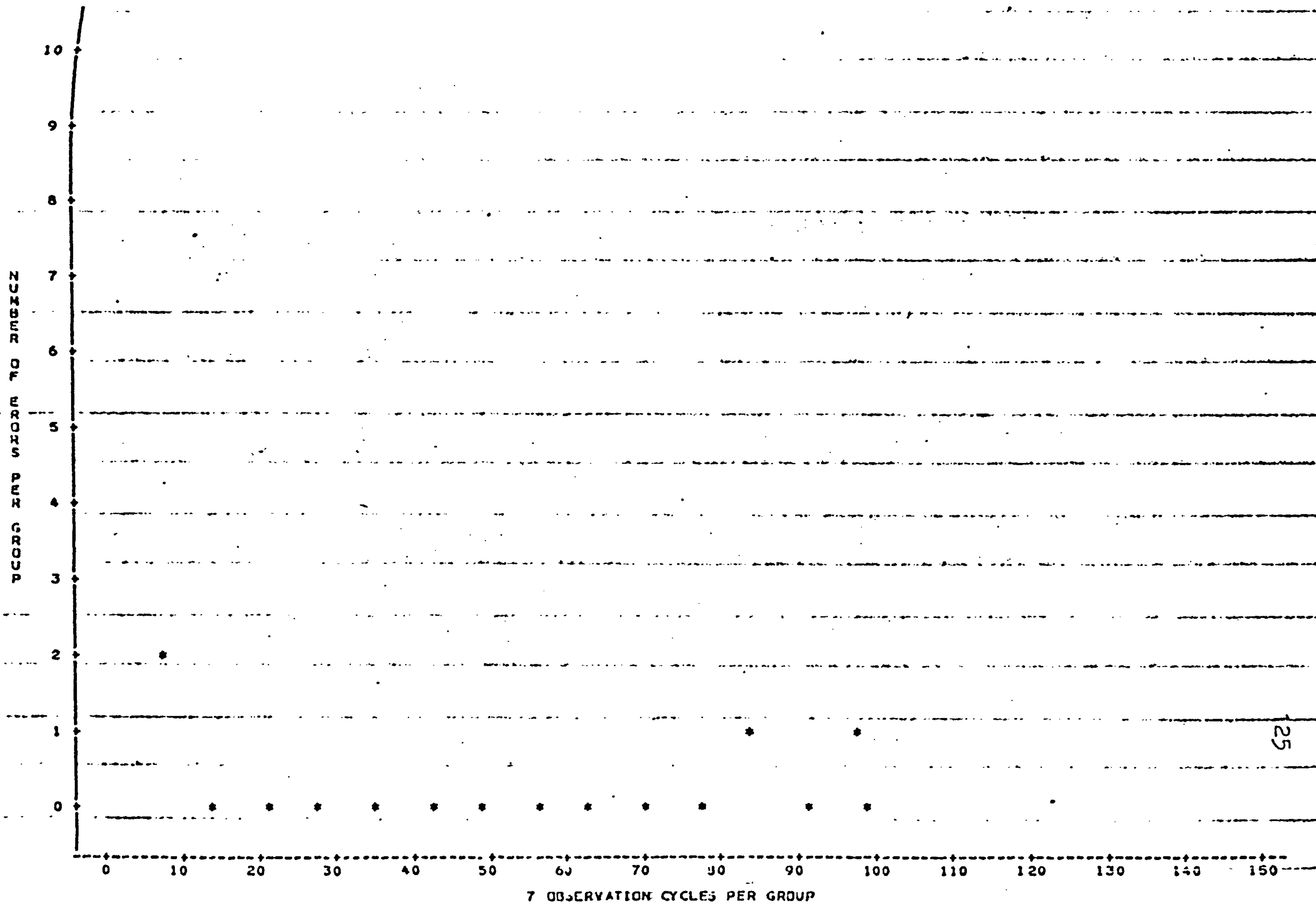


APPENDIX B.3

ERROR LEARNING CURVES - STUDY #1

ERROR LEARNING EFFECT 18:42 SUNDAY, JULY 9, 1978 346
SUBJNO=1 CONDNJ=46

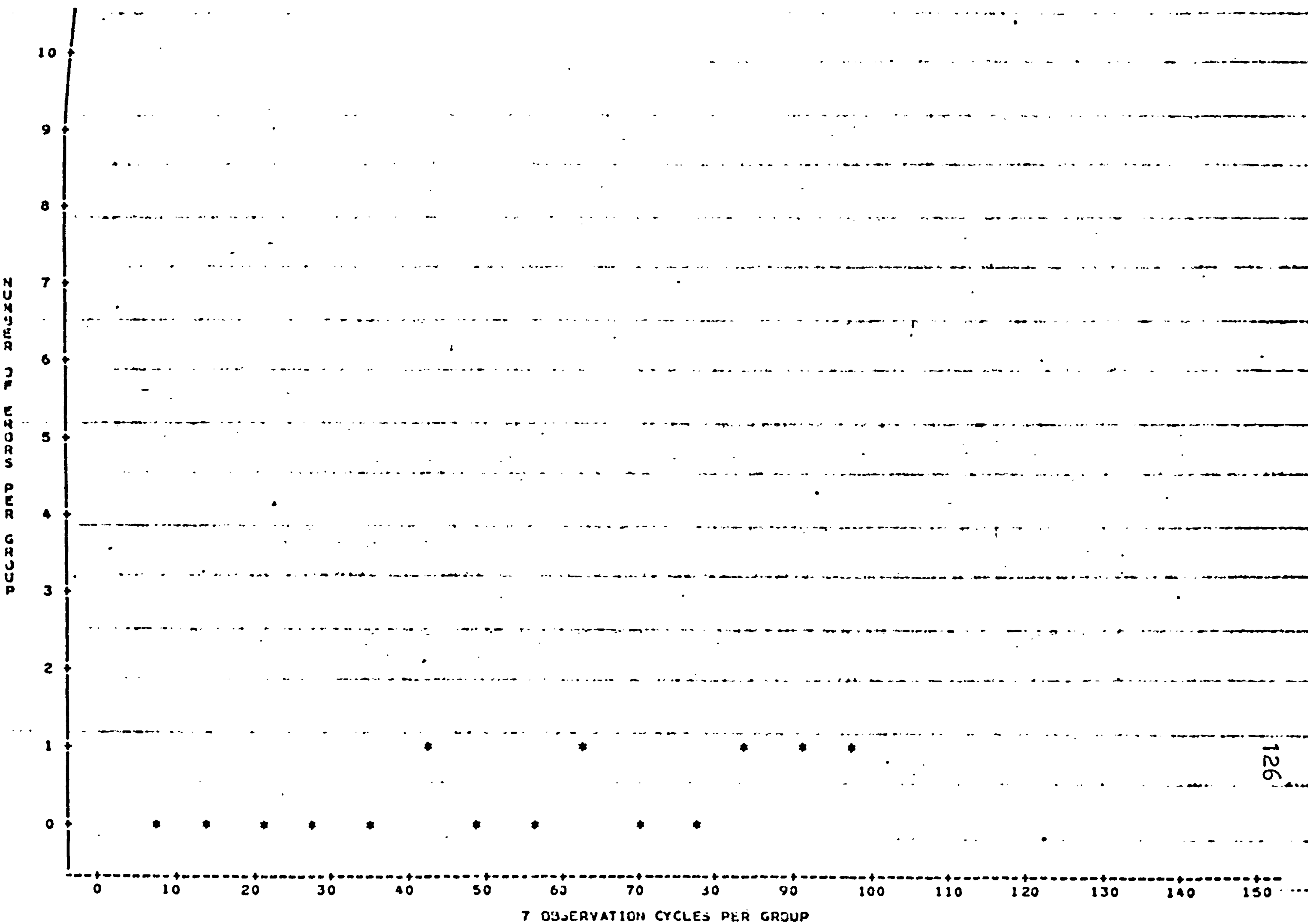
PLOT OF MNEROR*NOJBS SYMBOL USED IS *



NOTE: 84 OBS HAD MISSING VALUES OR WERE OUT [illegible]

ERROR LEARNING EFFECT
SUBJNO=2 CONDNO=46

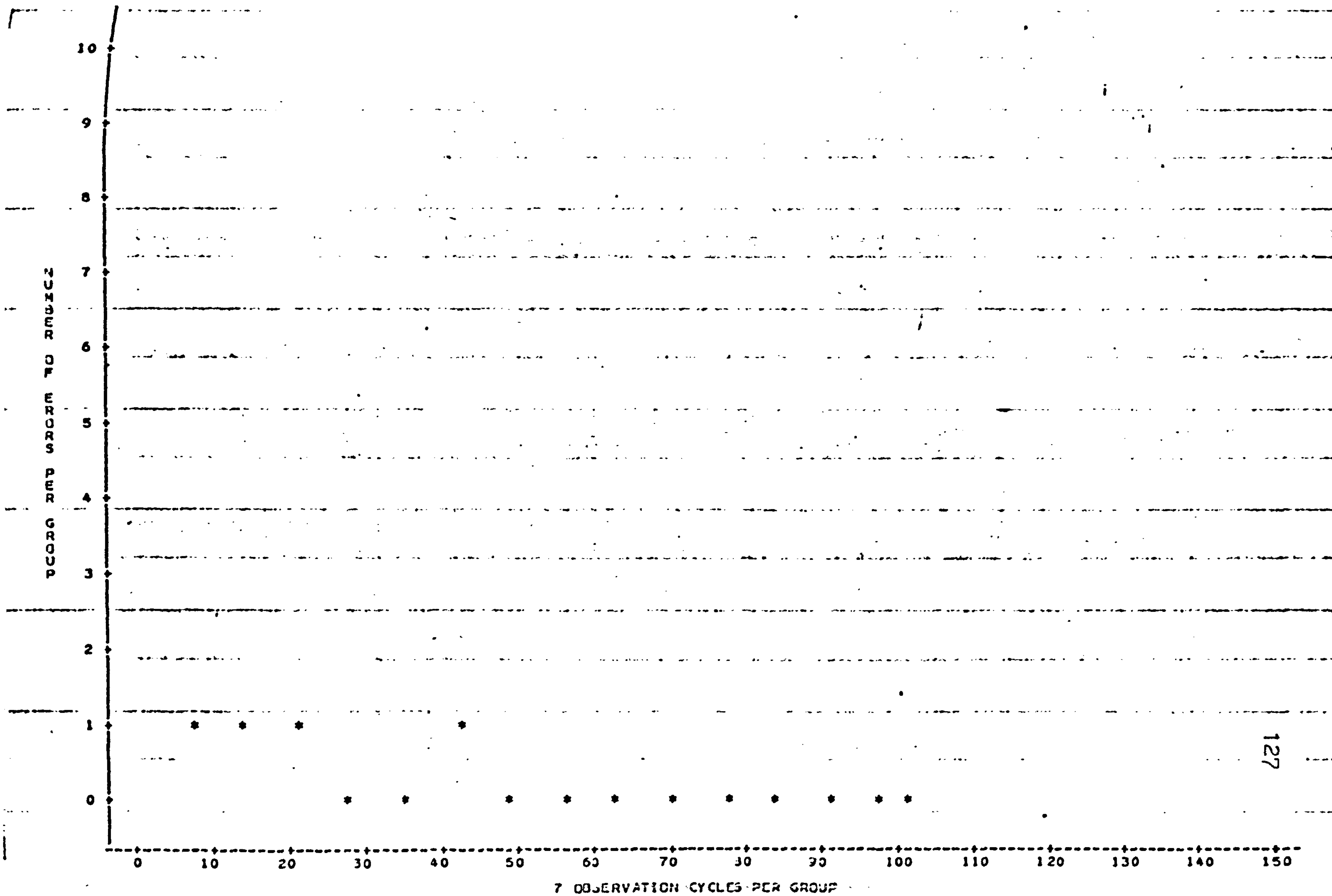
PLOT OF MNEROR*NOOBS SYMBOL USED IS *



NOTE: --- 83 OBS HAD MISSING VALUES OR WERE OUT OF RANGE

ERROR LEARNING EFFECT 18:42 SUNDAY, JULY 9, 1978 466
SUBJNO=3 CONDNJ=46

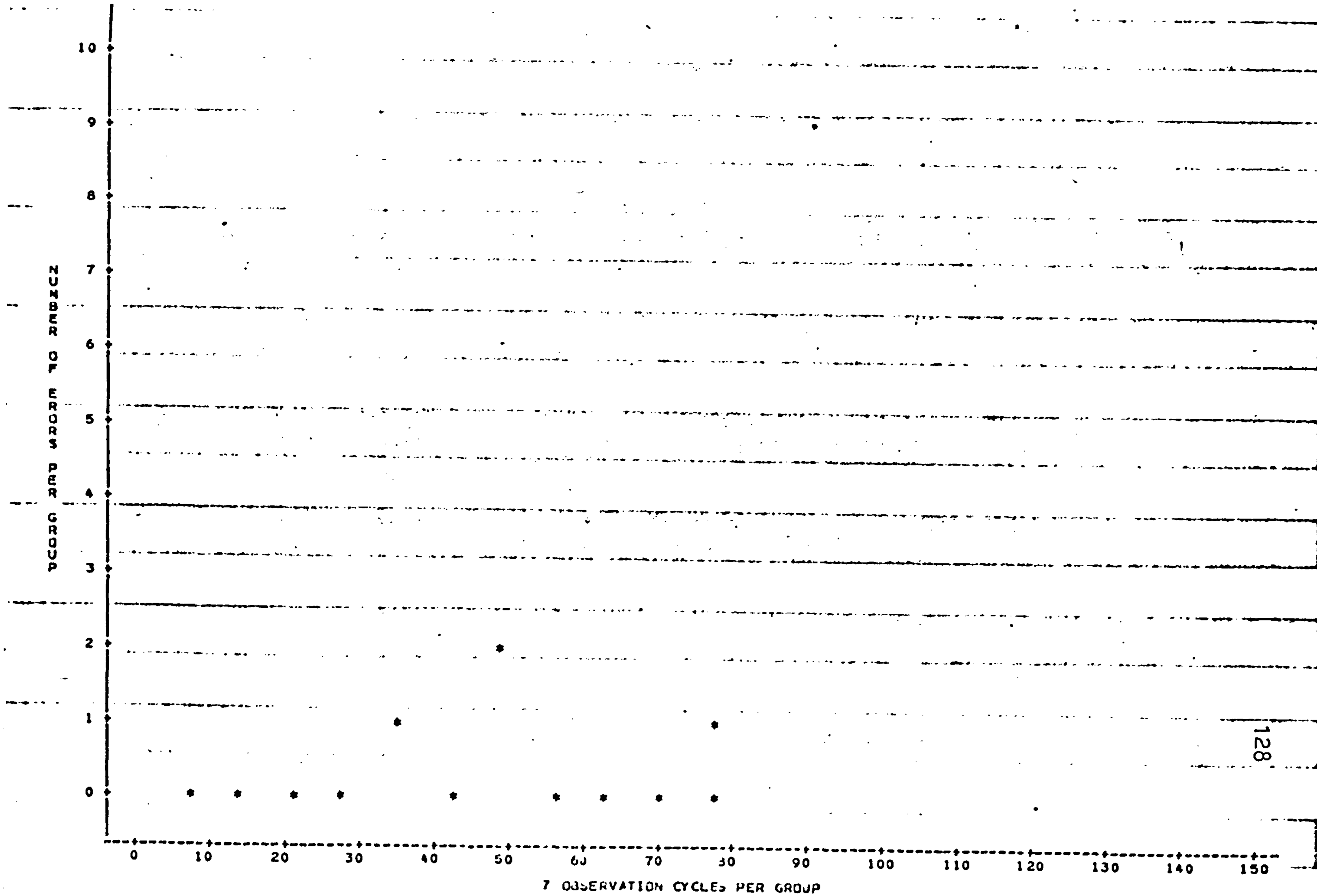
PLOT OF MNEROR*NOOBS SYMBOL USED IS *



NOTE: 84 OBS HAD MISSING VALUES OR WERE OUT OF RANGE

ERROR LEARNING EFFECT
SUBJNO=4 CONDNJ=46

PLOT OF MNEROR*NOJBS SYMBOL USED IS *

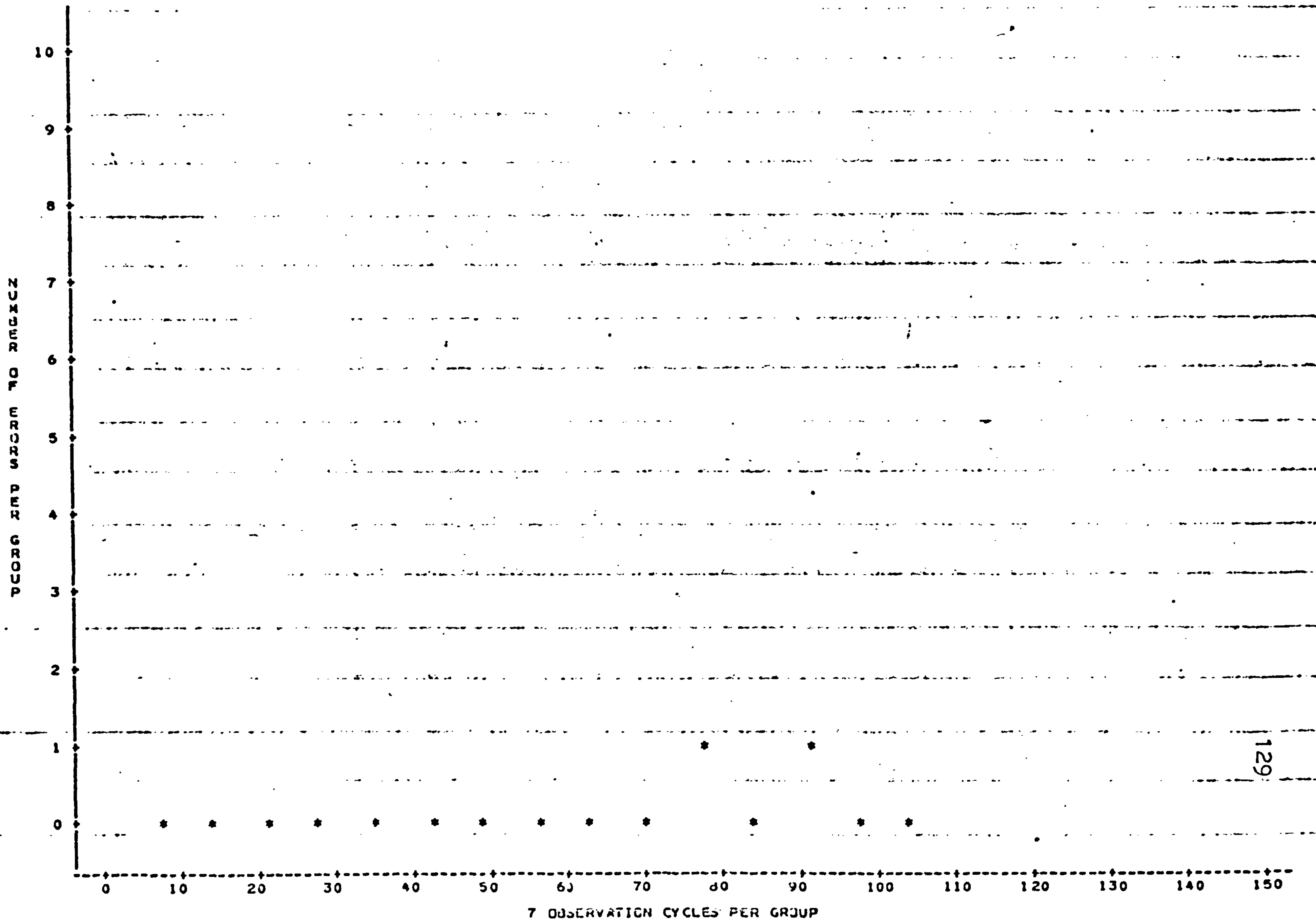


NOTE: 66 OBS

ERROR LEARNING EFFECT
SUBJNO=5 CONDNO=46

18:42 SUNDAY, JULY 9, 1978 586

PLOT OF MNEROR*NOBS SYMBOL USED IS *



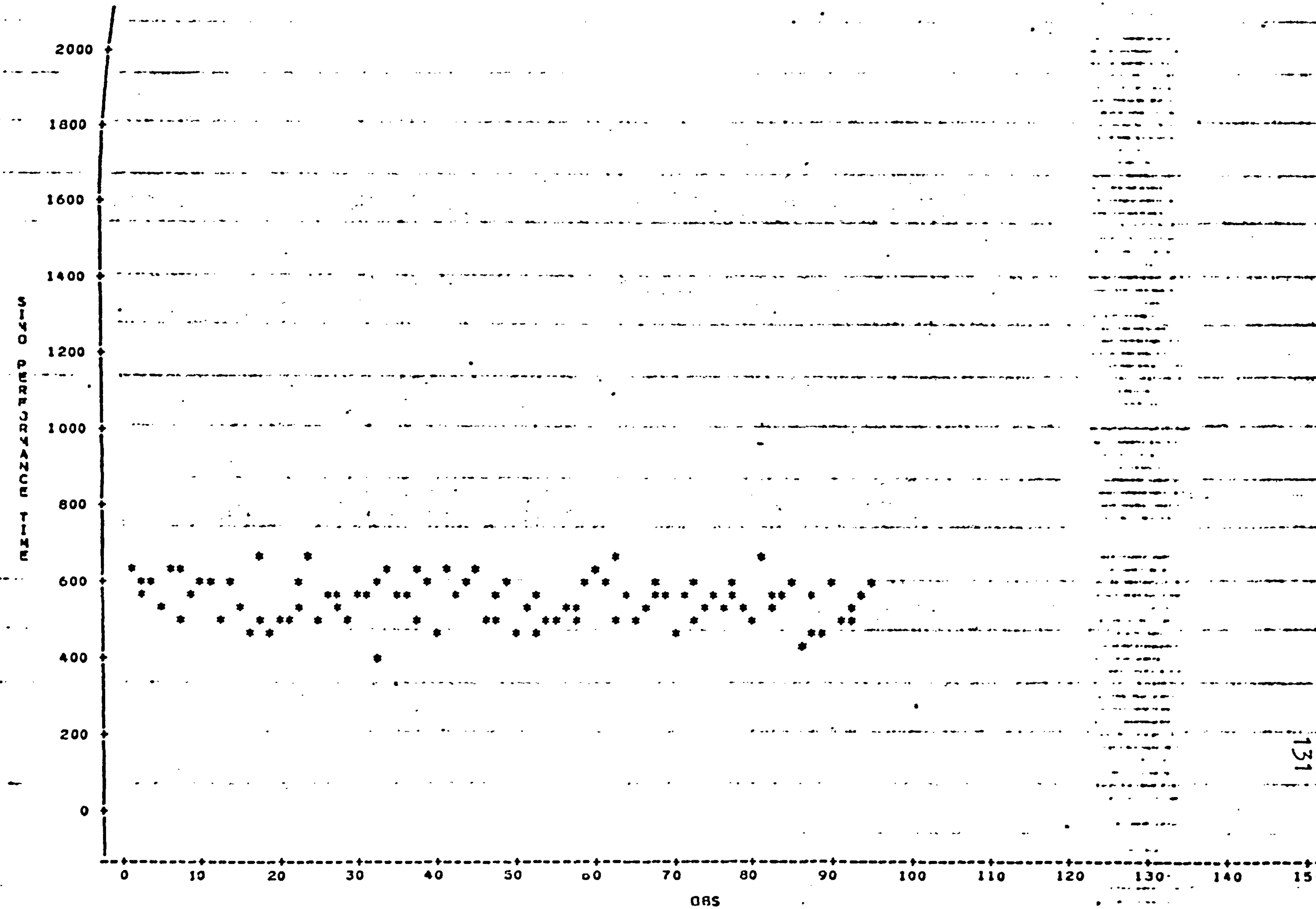
NOTE: 89 OBS HAD MISSING VALUES OR WERE OUT OF RANGE

APPENDIX B.4

LEARNING CURVES WITHOUT ERRORS - STUDY #1

SIMO LEARNING EFFECT FOR STUDY 1 23:54 FRIDAY, JULY 14, 1978 1256
SUBJNO=1 CONDNO=46

PLOT OF PT*OBS SYMBOL USED IS *



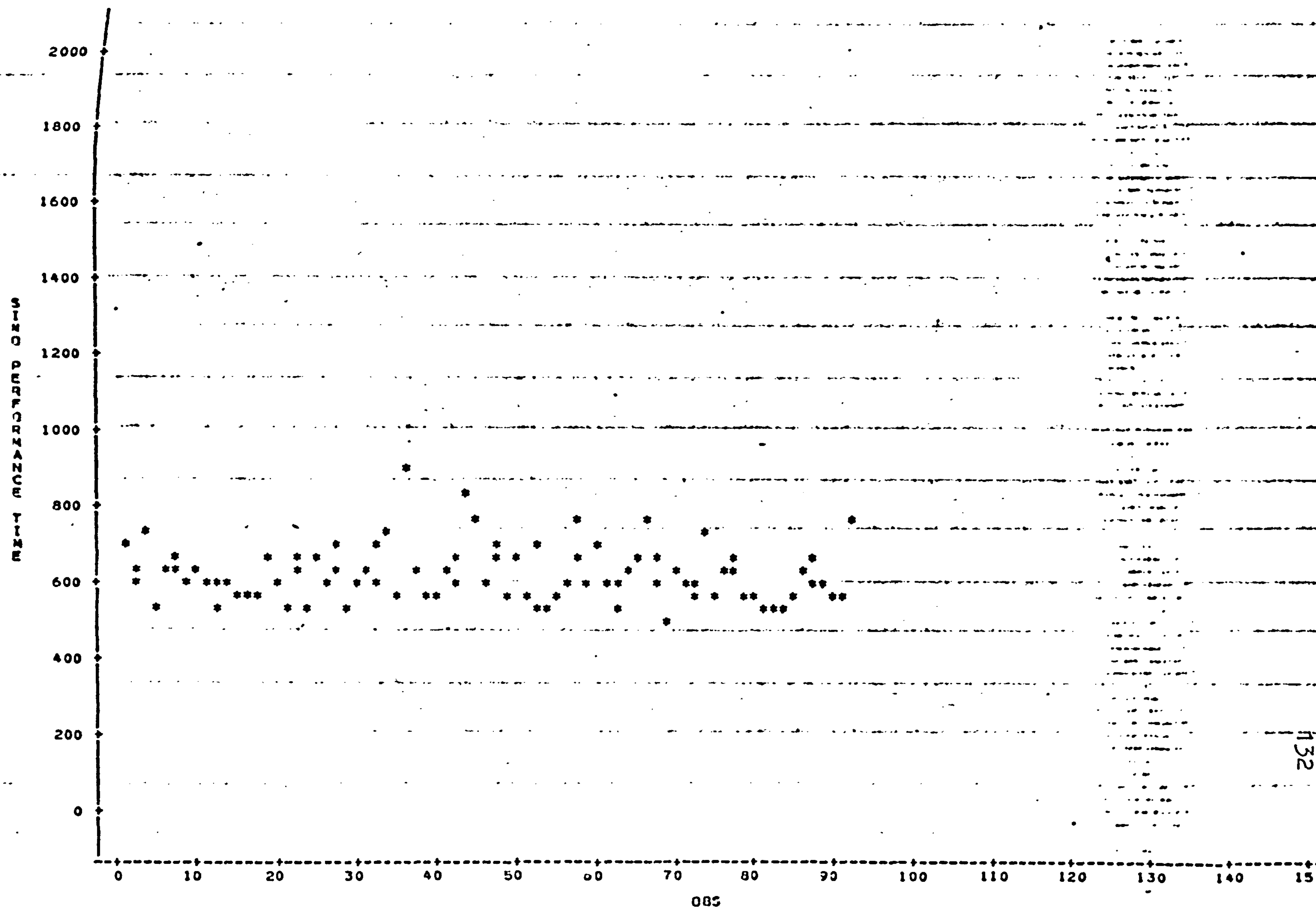
NOTE: 2 OBS HIDDEN

SIMO LEARNING EFFECT FOR STUDY 1
SUBJNO=2 CONDNO=46

23:54 FRIDAY, JULY 14, 1978 1316

132

PLOT OF PT*OBS SYMBOL USED IS *

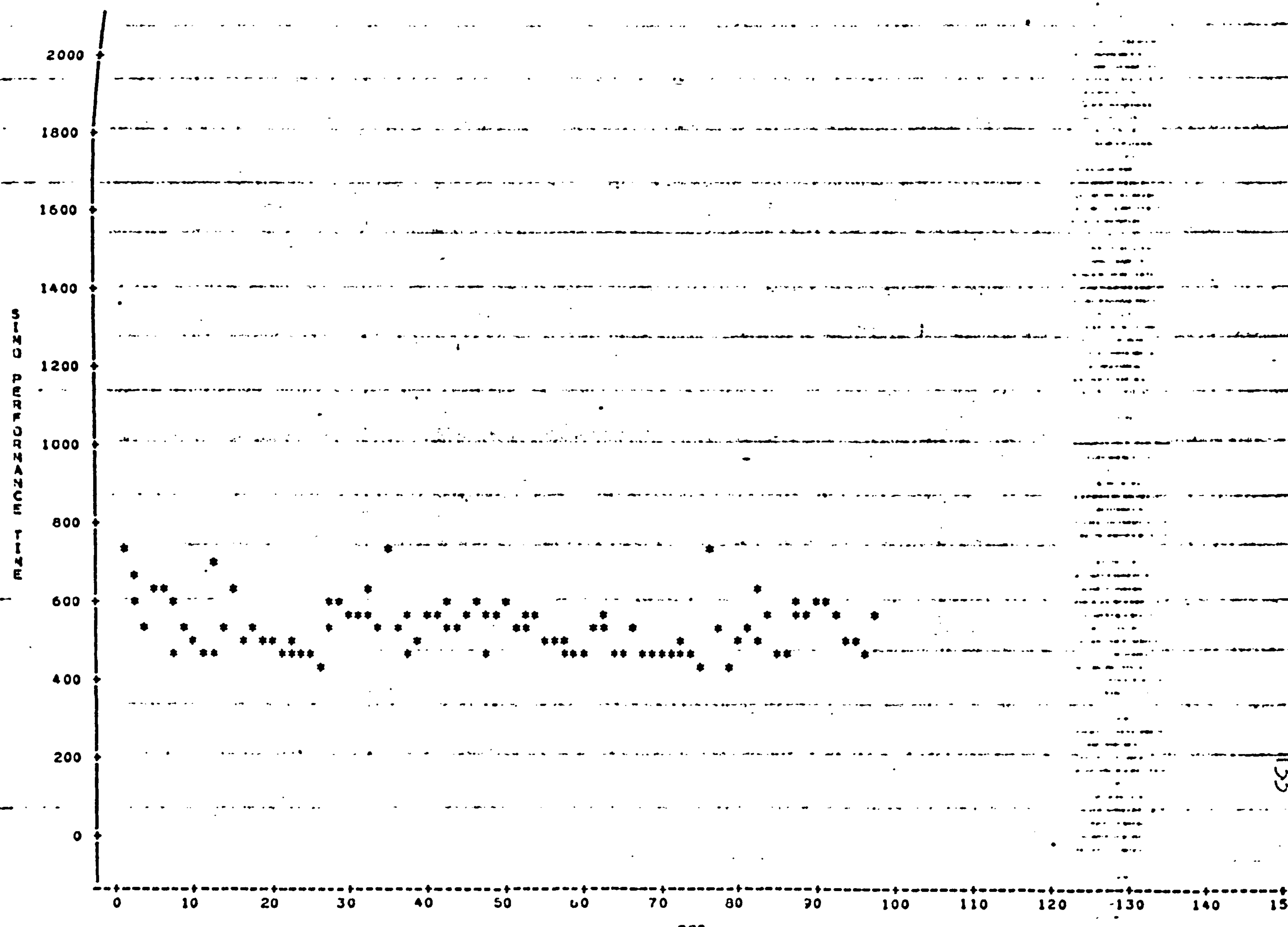


NOTE: 3 OBS HIDDEN

SIMO LEARNING EFFECT FOR STUDY 1
SUBJNO=3 CONDNO=46

23:54 FRIDAY, JULY 14, 1978 1376

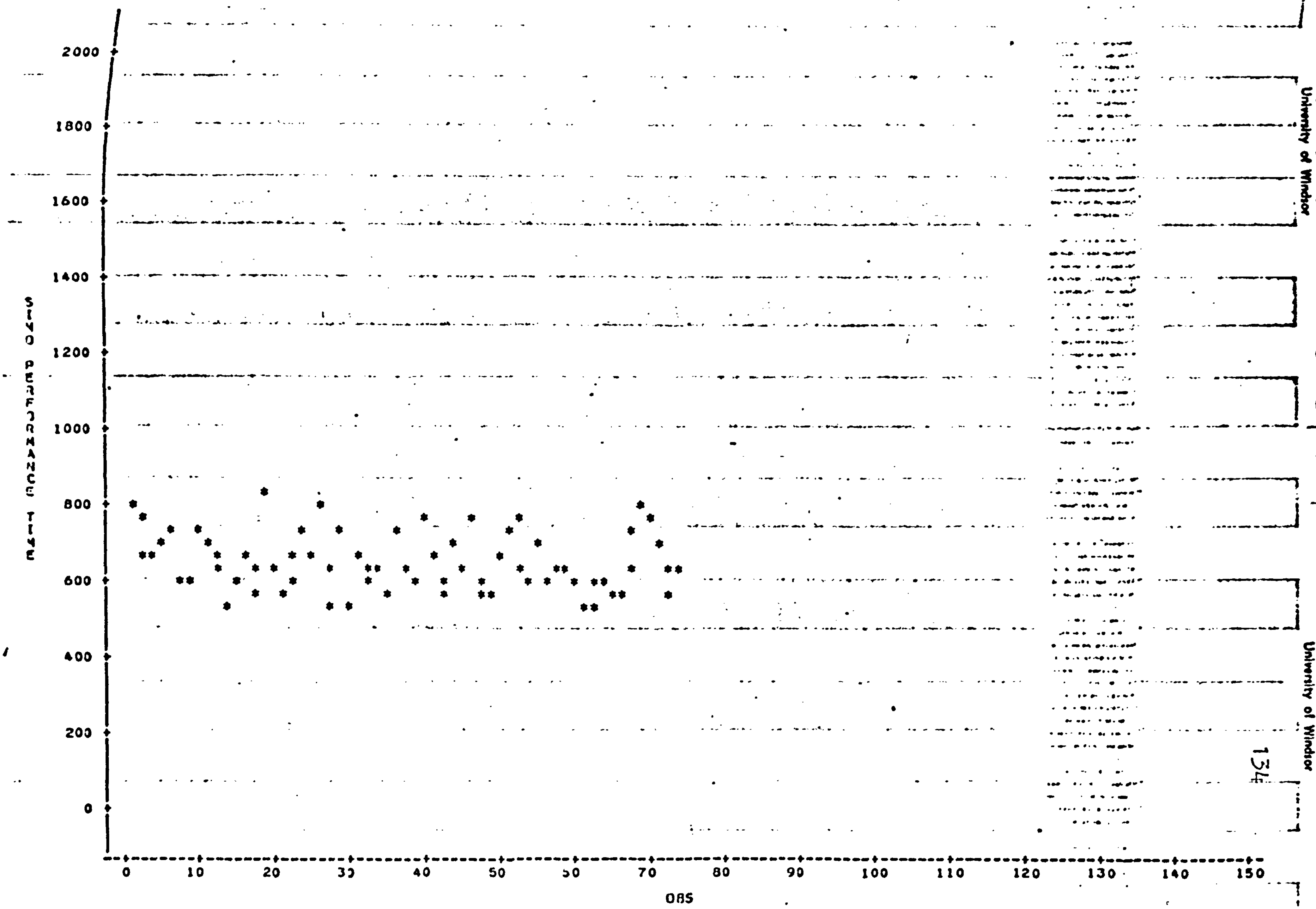
PLOT OF PT*OBS SYMBOL USED IS *



SIMJ LEARNING EFFECT FOR STUDY 1 .
SJBJNO=4   CONDNU=46

23:54 FRIDAY, JULY 14, 1978 1436

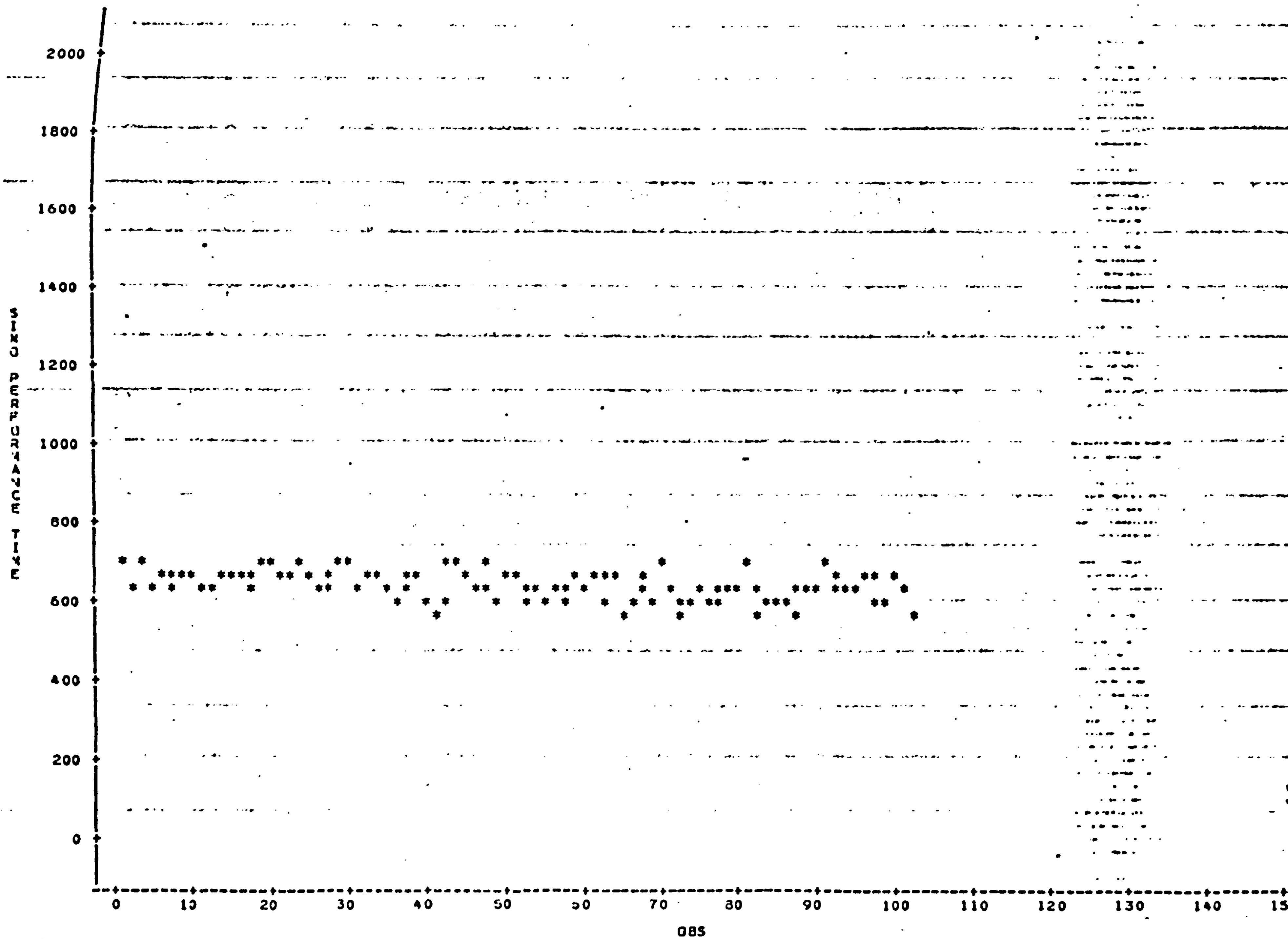
PLOT OF PT*OBS   SYMBOL USED IS *



NOTE: 3 OBS HIDDEN

SIMO LEARNING EFFECT FOR STUDY 1   23:54 FRIDAY, JULY 14, 1978 1496
SJBJNO=5   CONDNJ=46

PLOT OF PT*OBS   SYMBOL USED IS *



NOTE: 4 OBS HIDDEN

APPENDIX B.5

REGRESSION ANALYSIS FOR LEARNING - ASYM-SIMO

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: MEANPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	704.29642105	704.29642105	1.08	0.3130	0.059799	4.6199
ERROR	17	11073.34989474	651.37352322		STD DEV		MEANPT MEAN
CORRECTED TOTAL	18	11777.64631579			25.52202036		552.44210526

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
FOBS	1	704.29642105	1.08	0.3130	1	704.29642105	1.08	0.3130

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	563.55789474	46.24	0.0001	12.18847299
FOBS	-1.11157895	-1.04	0.3130	1.06899980

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL FOR MEAN	UPPER 95% CL FOR MEAN
1	588.00000000	562.44631579	25.55368421	538.68443307	586.20819851
2	583.80000000	561.33473684	22.46526316	539.46803489	583.20143879
3	547.80000000	560.22315789	-12.42315789	540.17691888	580.26939691
4	517.80000000	559.11157895	-41.31157895	540.78380066	577.43435723
5	555.00000000	558.00000000	-3.00000000	541.27366836	574.72633164
6	546.00000000	556.88842105	-10.88842105	541.59170256	572.18513955
7	558.00000000	555.77684211	2.22315789	541.69201040	569.86167381
8	549.00000000	554.66526316	-5.66526316	541.51426197	567.81626435
9	604.20000000	553.55368421	50.64631579	540.99627041	566.11109801
10	526.20000000	552.44210526	-26.24210526	540.08889067	564.79531986
11	512.40000000	551.33052632	-38.93052632	538.77311252	563.88794011
12	562.20000000	550.21894737	11.98105263	537.06794618	563.36594856
13	567.60000000	549.10736842	18.49263158	535.02253672	563.19220013
14	540.60000000	547.99578947	-7.39578947	532.69907098	563.29250797
15	552.60000000	546.88421053	5.71578947	530.15787889	563.61054216
16	549.60000000	545.77263158	3.82736842	527.44985330	564.09540986
17	583.20000000	544.66105263	38.53894737	524.61481361	564.70729165
18	511.20000000	543.54947368	-32.34947368	521.68277173	565.41617563
19	541.20000000	542.43789474	-1.23789474	518.67601202	566.19977746

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	11073.34989474
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.10497667
DURBIN-WATSON D	2.14454681

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: MEANPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	81.85263158	81.85263158	0.06	0.8121	0.003418	6.0170
ERROR	17	23863.60421053	1403.74142415			STD DEV	MEANPT MEAN
CORRECTED TOTAL	18	23945.45684211				37.46653739	622.67368421

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
FOBS	1	81.85263158	0.06	0.8121	1	81.85263158	0.06	0.8121

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	626.46315789	35.01	0.0001	17.89277935
FOBS	-0.37394737	-0.24	0.8121	1.56930056

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL FOR MEAN	UPPER 95% CL FOR MEAN
1	637.20000000	626.08421053	11.11578947	591.20156978	660.96685128
2	633.60000000	625.70526316	7.89473684	593.60476348	657.80576283
3	576.60000000	625.32631579	-48.72631579	595.89827079	654.75436079
4	594.00000000	624.94736842	-30.94736842	598.04937806	651.84535878
5	601.20000000	624.56842105	-23.36842105	600.01402760	649.12281451
6	618.00000000	624.18947368	-6.18947368	601.73376417	646.64518320
7	645.00000000	623.81052632	21.18947368	603.13387665	644.48717598
8	657.60000000	623.43157895	34.16842105	604.12580021	642.73735768
9	700.20000000	623.05263158	77.14736842	604.61824406	641.48701910
10	645.00000000	622.67368421	22.32631579	604.53906281	640.80830561
11	579.40000000	622.29473684	-42.89473684	603.86034932	640.72912436
12	666.60000000	621.91578947	44.68421053	602.61001074	641.22156821
13	608.40000000	621.53684211	-13.13684211	600.86019244	642.21349177
14	627.00000000	621.15789474	5.84210526	598.70218522	643.61360425
15	616.20000000	620.77894737	-4.57894737	596.22455391	645.33334082
16	615.60000000	620.40000000	-4.80000000	593.50200964	647.29799036
17	544.80000000	620.02105263	-75.22105263	590.59300763	649.44909763
18	605.40000000	619.64210526	-14.24210526	587.54160559	651.74260494
19	660.00000000	619.26315789	40.73684211	584.38051715	654.14579864

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	23863.60421053
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	0.18608571
DURBIN-WATSON D	1.56721443

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: MEANPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	3355.09727820	3355.09727820	1.93	0.1816	0.096902	7.7793
ERROR	18	31268.60472181	1737.14470677		STD DEV		MEANPT MEAN
CORRECTED TOTAL	19	34623.70200000			41.67906797		535.77000000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	OF	TYPE IV SS	F VALUE	PR > F
FOBS	1	3355.09727820	1.93	0.1816	1	3355.09727820	-1.93	0.1816

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	559.35473684	28.89	0.0001	19.36123913
FOBS	-2.24616541	-1.39	0.1816	1.61624493

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL FOR MEAN	UPPER 95% CL FOR MEAN
1	636.60000000	557.10357143	79.49142857	519.37329615	594.84384671
2	546.00000000	554.86240602	-8.86240602	519.98531348	589.73949855
3	559.80000000	552.61624060	7.18375940	520.49254060	584.73994060
4	520.20000000	550.37007519	-30.17007519	520.86562544	579.87452494
5	473.40000000	548.12390977	-74.72390977	521.06558493	575.18223462
6	537.60000000	545.87774436	-8.27774436	521.04121345	570.71427527
7	601.80000000	543.63157895	58.16842105	520.72713557	566.53602233
8	534.60000000	541.38541353	-6.78541353	520.04452037	562.72630669
9	556.80000000	539.13924812	17.66075188	519.90774174	559.37075450
10	558.60000000	536.89308271	21.70691729	517.23973909	556.54642632
11	538.20000000	534.64691729	3.55308271	514.99357368	554.30026091
12	483.00000000	532.40075188	-49.40075188	512.16924550	552.63225826
13	510.60000000	530.15458647	-19.55458647	508.81369331	551.49547963
14	479.40000000	527.90842105	-48.50842105	505.00397767	550.81286443
15	462.00000000	525.66225564	-63.66225564	500.82572473	550.49878655
16	543.00000000	523.41609023	19.58390977	496.35776538	550.47441507
17	538.20000000	521.16992481	17.03007519	491.66547506	550.67437456
18	569.40000000	518.92375940	50.47624060	486.80005940	551.04745940
19	556.20000000	516.67759398	39.52240602	481.80050145	551.55468652
20	510.00000000	514.43142857	-4.43142857	476.69615329	552.16670385

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	31268.60472180
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	0.28457279
DURBIN-WATSON D	1.28905179

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: MEANPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	2278.57700893	2278.57700893	1.70	0.2154	0.115421	5.6633
ERROR	13	17462.87199107	1343.29784547		STD DEV		MEANPT MEAN
CORRECTED TOTAL	14	19741.44900000			36.65102789		647.17000000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
FOBS	1	2278.57700893	1.70	0.2154	1	2278.57700893	1.70	0.2154

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	669.99142857	33.64	0.0001	19.91463525
FOBS	-2.85267857	-1.30	0.2154	2.19031785

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL FOR MEAN	UPPER 95% CL FOR MEAN
1	721.20000000	667.13875000	54.06125000	628.21434844	706.06315156
2	654.60000000	664.28607143	-9.68607143	629.29994596	699.27219690
3	630.60000000	661.43339286	-30.83339286	630.16471105	692.70207467
4	664.20000000	658.58071429	5.61928571	630.72010595	686.44132262
5	645.60000000	655.72803571	-10.12803571	630.83871915	680.61735228
6	643.80000000	652.87535714	-9.07535714	630.34705918	675.40365511
7	620.40000000	650.02267857	-29.62267857	629.03811550	671.00724165
8	674.40000000	647.17000000	27.23000000	626.72590272	667.61409728
9	637.20000000	644.31732143	-7.11732143	623.33275835	665.30188450
10	627.00000000	641.46464286	-14.46464286	618.93634489	663.99294082
11	678.60000000	638.61196429	39.98803571	613.72264772	663.50128085
12	617.40000000	635.75928571	-18.35928571	607.89867738	663.61989405
13	559.80000000	632.90660714	-73.10660714	601.63792533	664.17528895
14	693.00000000	630.05392857	62.94607143	595.06780310	665.04005404
15	639.75000000	627.20125000	12.54875000	588.27684844	666.12565156

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	17462.87199107
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.30096712
DURBIN-WATSON D	2.37039761

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: MEANPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	5203.12020779	5203.12020779	39.62	0.0001	0.675880	1.7885
ERROR	19	2495.17122079	131.32480109		STD DEV		MEANPT MEAN
CORRECTED TOTAL	20	7698.29142858			11.45970336		640.75714286

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
FOBS	1	5203.12020779	39.62	0.0001	1	5203.12020779	39.62	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	669.35142857	129.08	0.0001	5.18558737
FOBS	-2.59948052	-6.29	0.0001	0.41297904

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL FOR MEAN	UPPER 95% CL FOR MEAN
1	663.00000000	666.75194805	-3.75194805	656.64708969	676.85680642
2	667.80000000	664.15246753	3.64753247	654.77629360	673.52864146
3	653.40000000	661.55298701	-8.15298701	652.88053763	670.22543640
4	660.00000000	658.95350649	1.04649351	650.95323245	666.95378054
5	667.80000000	656.35402597	11.44597403	648.98573871	663.72231324
6	669.60000000	653.75454545	15.84545455	646.96682159	660.54226932
7	660.60000000	651.15506494	9.44493506	644.88218687	657.42794300
8	638.40000000	648.55558442	-10.15558442	642.71443136	654.39673747
9	642.60000000	645.95610390	-3.35610390	640.44398356	651.46821823
10	645.60000000	643.35662338	2.24337662	638.05171944	648.66152731
11	625.80000000	640.75714286	-14.95714286	635.52313169	645.99115402
12	630.60000000	638.15766234	-7.55766234	632.85275840	643.46256628
13	639.60000000	635.55818182	4.04181818	630.04606748	641.07029616
14	639.60000000	632.95870130	6.64129870	627.11754825	638.79985435
15	610.20000000	630.35922078	-20.15922078	624.08634271	636.63209885
16	619.80000000	627.75974026	-7.95974026	620.97201639	634.54746413
17	621.00000000	625.16025974	-4.16025974	617.79197248	632.52854700
18	615.60000000	622.56077922	-6.96077922	614.56050517	630.56105327
19	646.20000000	619.96129870	26.23870130	611.28884932	628.63374808
20	631.20000000	617.36181818	13.83818182	607.98564425	626.73799211
21	607.50000000	614.76233766	-7.26233766	604.65747930	624.86719603

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	2495.17122078
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000001
FIRST ORDER AUTOCORRELATION	0.18933165
DURBIN-WATSON D	1.59963918

APPENDIX B.6

DUNCAN'S MEANS RANGE TESTS FOR LEARNING - STUDY #1

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   23:54 FRIDAY, JULY 14, 1978   188

SUBJNO=1   CONDNJ=46

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=90   MS=3385.28

GROUPING	MEAN	N	OBS
A	559.350000	20	1
A	552.600000	20	4
A	552.000000	20	2
A	551.250000	20	3
A	545.200000	15	5

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   23:54 FRIDAY, JULY 14, 1978   429

SUBJNC=2   CONDNJ=46

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=87   MS=4727.77

GROUPING		MEAN	N	OBS
	A	647.550000	20	3
B	A	630.450000	20	2
B	A	616.800000	20	4
B	A	610.350000	20	1
B		589.250000	12	5

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   23:54 FRIDAY, JULY 14, 1978 670

SUBJNO=3 CONDNO=46

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=92   MS=4210.86

GROUPING	MEAN	N	OBS
A	565.650000	20	1
A	549.352941	17	5
B A	536.850000	20	2
B A	534.150000	20	3
B	498.750000	20	4

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   23:54 FRIDAY, JULY 14, 1978 910

SUBJNO=4 CONDNO=46

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=70   MS=5600.95

GROUPING	MEAN	N	OBS
A	667.650000	20	1
A	646.050000	20	2
A	640.050000	20	3
A	630.214286	14	4

```
S T A T I S T I C A L   A N A L Y S I S   S Y S T E M        23:54 FRIDAY, JULY 14, 1978 1154
                        SUBJNO=5   CONDNU=46

                    GENERAL LINEAR MODELS PROCEDURE

              DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

        MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

        ALPHA LEVEL=.05        DF=96        MS=1060.22

        GROUPING                  MEAN       N    OBS

               A            661.050000      20      1
               A
               A            659.100000      20      2

               B            636.150000      20      3
               B
               B            628.500000      20      5
               B
               B            627.300000      20      4
               B
               B            607.500000       2      6
```

APPENDIX B.7

ANOVA - STUDY #1

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   23:00 SATURDAY, JUNE 10, 1978   101

ANALYSIS OF VARIANCE PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
SUBJNO	5	1 2 3 4 5
R	2	1 2
L	2	1 2
A	5	1 2 3 4 5
S	3	1 2 3

NUMBER OF OBSERVATIONS IN DATA SET = 6000

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: PT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	299	60116097.56849414	201057.18250332	54.71	0.0001	0.741577	10.6868
ERROR	5700	20949139.35000604	3675.28760526		STD DEV		PT MEAN
CORRECTED TOTAL	5999	81065236.91850018			60.62415035		567.28050000

SOURCE	DF	ANOVA SS	F VALUE	PR > F
SUBJNO	4	9838720.86599994	669.25	0.0001
R	1	14639492.52150011	3983.22	0.0001
SUBJNO*R	4	400065.02599972	27.21	0.0001
L	1	18036986.47350007	4907.64	0.0001
SUBJNO*L	4	917803.34399974	62.43	0.0001
R*L	1	171767.10149974	46.74	0.0001
SUBJNO*R*L	4	265123.23600018	18.03	0.0001
A	4	1191340.29599994	81.04	0.0001
SUBJNO*A	16	1031394.65899973	17.54	0.0001
R*A	4	43173.42509964	2.94	0.0194
SUBJNO*R*A	16	761722.53900003	12.95	0.0001
L*A	4	631141.83399969	42.93	0.0001
SUBJNO*L*A	16	720736.91099989	12.26	0.0001
R*L*A	4	285093.55600035	19.39	0.0001
SUBJNO*R*L*A	16	310545.66899937	5.28	0.0001
S	2	2887804.03899993	392.87	0.0001
SUBJNO*S	8	459419.95599973	15.63	0.0001
R*S	2	121291.52699995	16.50	0.0001
SUBJNO*R*S	8	250883.59799993	8.53	0.0001
L*S	2	82567.11399990	11.23	0.0001
SUBJNO*L*S	8	268521.32600003	9.13	0.0001
R*L*S	2	34625.31300002	4.71	0.0090
SUBJNO*R*L*S	8	183247.15199924	6.23	0.0001
A*S	8	196864.01099974	6.70	0.0001
SUBJNO*A*S	32	1744090.41899970	14.83	0.0001
R*A*S	8	128616.55299949	4.37	0.0001
SUBJNO*R*A*S	32	1393702.41699910	11.85	0.0001
L*A*S	8	268915.61100000	9.15	0.0001
SUBJNO*L*A*S	32	1283983.05899881	10.92	0.0001
R*L*A*S	8	173150.72699934	5.89	0.0001
SUBJNO*R*L*A*S	32	1393085.18300056	11.85	0.0001

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R	1	14639492.52150011	146.37	0.0003

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*L AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
L	1	18036986.47350007	78.61	0.0009

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*A AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
A	4	1191340.29599994	4.62	0.0114

DEPENDENT VARIABLE: PT

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*S AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
S	2	2887804.03899993	25.14	0.0004

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*L AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*L	1	171767.10149974	2.59	0.1827

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*A AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*A	4	43173.42599964	0.23	0.9104

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*S AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*S	2	121291.52699995	1.93	0.2065

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*L*S AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
L*S	2	82567.11899990	1.23	0.3422

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*A*S AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
A*S	8	196864.01099974	0.45	0.8804

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*L*A AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
L*A	4	631143.83399969	3.50	0.0309

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*L*A AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*L*A	4	285098.55600035	3.67	0.0264

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*L*S AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*L*S	2	34625.31300002	0.76	0.5004

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ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: PT

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*A*S AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*A*S	8	128618.56299989	0.37	0.9292

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*L*A*S AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
L*A*S	8	268915.61130000	0.84	0.5767

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*L*A*S AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*L*A*S	8	173150.72699934	0.50	0.8490

APPENDIX B.8

DUNCAN'S MEANS TESTS ON LEVELS OF SIGNIFICANCE OF MAIN VARIABLES - A AND S

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=5940   MS=7099.73

GROUPING	MEAN	N	A
A	584.055000	1200	1
A			
A	582.520000	1200	2
B	563.057500	1200	3
B			
B	559.515000	1200	4
C	547.255000	1200	5

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=5940   MS=7099.73

GROUPING	MEAN	N	S
A	593.697000	2000	3
B	568.164000	2000	2
C	539.980500	2000	1

APPENDIX C.0

STUDY #2 - ASYMMETRICAL AND SYMMETRICAL SIMULTANEOUS 2-HAND REACH MOTIONS

Condition Number	R	L	A	S	Condition Number	R	L	A	S
1	3	3	45	2	17	3	3	90	2
2	6				18	6			
3	9				19	9			
4	12				20	12			
5	3	6			21	3	6		
6	6				22	6			
7	9				23	9			
8	12				24	12			
9	3	9			25	3	9		
10	6				26	6			
11	9				27	9			
12	12				28	12			
13	3	12			29	3	12		
14	6				30	6			
15	9				31	9			
16	12				32	12			

Table C1 : Experimental Conditions for Asymmetrical and Symmetrical Simultaneous Reach Motions

Condition Number	Experimental Condition				Condition Number	Experimental Condition			
	R	L	A	S		R	L	A	S
33	3	3	45	10	49	3	3	90	10
34	6				50	6			
35	9				51	9			
36	12				52	12			
37	3	6			53	3	6		
38	6				54	6			
39	9				55	9			
40	12				56	12			
41	3	9			57	3	9		
42	6				58	6			
43	9				59	9			
44	12				60	12			
45	3	12			61	3	12		
46	6				62	6			
47	9				63	9			
48	12				64	12			

Table C1 continued

Experimental design model: randomized mixed-nested factorial design

Main Effects	Symbol	Level	Type
Distance traveled by right hand	R_i	4	Fixed
Distance traveled by left hand	L_j	4	Fixed
Starting separation distance	S_k	2	Fixed
Angle of reach	A_l	2	Fixed
Handedness of subjects	H_m	2	Fixed
Subject	$O_{p(m)}$	7	Random
Residual	$E_{n(ijklmp)}$	20	Random

Table C2: EMS Table - Study #2

$$EMS = a\,\sigma_e^2 + b\,\sigma_x^2 + c\,\phi_y$$

Source	R	L	S	A	H	O	R_n	a	b	x	c	y
R_i	0	4	2	2	2	7	20	1	320	RO	4480	R
L_j	4	0	2	2	2	7	20	1	320	LO	4480	L
S_k	4	4	0	2	2	7	20	1	640	SO	8960	S
A_l	4	4	2	0	2	7	20	1	640	AO	8960	A
H_m	4	4	2	2	0	7	20	1	1280	O	8960	H
$O_{p(m)}$	4	4	2	2	1	1	20	1	1280	O		
$(R*L)_{ij}$	0	0	2	2	2	7	20	1	80	RLO	1120	RL
$(R*S)_{ik}$	0	4	0	2	2	7	20	1	160	RSO	2240	RS
$(R*A)_{il}$	0	4	2	0	2	7	20	1	160	RAO	2240	RA
$(R*H)_{im}$	0	4	2	2	0	7	20	1	320	RO	2240	RH
$(R*O)_{ip(m)}$	0	4	2	2	1	1	20	1	320	RO		
$(L*S)_{jk}$	4	0	0	2	2	7	20	1	160	LSO	2240	LS
$(L*A)_{jl}$	4	0	2	0	2	7	20	1	160	LAO	2240	LA
$(L*H)_{jm}$	4	0	2	2	0	7	20	1	320	LO	2240	LH
$(L*O)_{jp(m)}$	4	0	2	2	1	1	20	1	320	LO		
$(S*A)_{kl}$	4	4	0	0	2	7	20	1	320	SAO	4480	SA
$(S*H)_{km}$	4	4	0	2	0	7	20	1	640	SO	4480	SH

Table C2 : EMS Table - Study #2

$$EMS = a\,\sigma_e^2 + b\,\sigma_x^2 + c\,\phi_y$$

Source	R	L	S	A	H	O	R_n	a	b	x	c	y
$(S*O)_{kp(m)}$	4	4	0	2	1	1	20	1	640	SO		
$(A*H)_{lm}$	4	4	2	0	0	7	20	1	640	AO	4480	AH
$(A*O)_{lp(m)}$	4	4	2	0	1	1	20	1	640	AO		
$(R*L*S)_{ijk}$	0	0	0	2	2	7	20	1	40	RLSO	560	RLS
$(R*L*A)_{ijl}$	0	0	2	0	2	7	20	1	40	RLAO	560	RLA
$(R*L*H)_{ijm}$	0	0	2	2	0	7	20	1	80	RLO	560	RLH
$(R*L*O)_{ijp(m)}$	0	0	2	2	1	1	20	1	80	RLO		
$(R*S*A)_{ikl}$	0	4	0	0	2	7	20	1	80	RSAO	1120	RSA
$(R*S*H)_{ikm}$	0	4	0	2	0	7	20	1	160	RSHO	1120	RSH
$(R*S*O)_{ikp(m)}$	0	4	0	2	1	1	20	1	160	RSO		
$(R*A*H)_{ilm}$	0	4	2	0	0	7	20	1	160	RAO	1120	RAH
$(R*A*O)_{ilp(m)}$	0	4	2	0	1	1	20	1	160	RAO		
$(L*S*A)_{jkl}$	4	0	0	0	2	7	20	1	80	LSAO	1120	LSA
$(L*S*H)_{jkm}$	4	0	0	2	0	7	20	1	160	LSO	1120	LSH
$(L*S*O)_{jkp(m)}$	4	0	0	2	1	1	20	1	160	LSO		
$(L*A*H)_{jl}$	4	0	2	0	0	7	20	1	160	LAO	1120	LAH
$(L*A*O)_{jlp(m)}$	4	0	2	0	1	1	20	1	160	LAO		

Table C2 continued

$$EMS = a\,\sigma_e^2 + b\,\sigma_x^2 + c\,\phi_y$$

Source	R	L	S	A	H	O	R_n	a	b	x	c	y
$(S*A*H)_{klm}$	4	4	0	0	0	7	20	1	320	SAO	2240	SAH
$(S*A*O)_{klp(m)}$	4	4	0	0	1	1	20	1	320	SAO		
$(R*L*S*A)_{ijkl}$	0	0	0	0	2	7	20	1	20	RLASO	280	RLAS
$(R*L*S*H)_{ijkm}$	0	0	0	2	0	7	20	1	40	RLSO	280	RLSH
$(R*L*S*O)_{ijkp(m)}$	0	0	0	2	1	1	20	1	40	RLSO		
$(R*L*A*H)_{ijlm}$	0	0	2	0	0	7	20	1	40	RLAO	280	RLAH
$(R*L*A*O)_{ijlp(m)}$	0	0	2	0	1	1	20	1	40	RLAO		
$(R*S*A*H)_{iklm}$	0	4	0	0	0	7	20	1	80	RSAO	560	RSAH
$(R*S*A*O)_{iklp(m)}$	0	4	0	0	1	1	20	1	80	RSAO		
$(L*S*A*H)_{jklm}$	4	0	0	0	0	7	20	1	80	LSAO	560	LSAH
$(L*S*A*O)_{jklp(m)}$	4	0	0	0	1	1	20	1	80	LSAO		
$(R*L*S*A*H)_{ijklm}$	0	0	0	0	0	7	20	1	20	RLASO	140	RLASH
$(R*L*S*A*O)_{ijklp(m)}$	0	0	0	0	1	1	20	1	20	RLSAO		
$E_{n(ijklmp)}$	1	1	1	1	1	1	1	1				

Table C2 continued

Table C3 : Visual Search Frequency Table

A=45°, S=2"

Combine (top face)

R		L 3	L 6	L 9	L 12
12	Mean	532.47	571.35	609.39	652.37
12	PR<PL	15.00	16.75	26.46	36.05
12	PR>PL	82.85	79.66	7[illegible].00	61.75
9	Mean	487.52	509.98	566.01	603.24
9	PR<PL	12.85	36.45	39.25	44.60
9	PR>PL	83.90	58.90	56.45	51.45
6	Mean	420.91	475.32	533.96	545.63
6	PR<PL	12.15	40.70	50.00	52.85
6	PR>PL	85.35	55.35	45.35	45.35
3	Mean	336.69	442.47	465.54	518.83
3	PR<PL	33.20	60.00	81.45	63.25
3	PR>PL	58.20	36.75	15.35	33.95

Right-handed Subjects (left face)

L		R 3	R 6	R 9	R 12
12	Mean	518	546	613	659
12	PR<PL	72.9	54.3	52.1	35.7
12	PR>PL	25.0	44.3	43.6	61.4
9	Mean	473	524	541	620
9	PR<PL	87.9	52.1	42.1	29.3
9	PR>PL	10.0	40.7	52.9	67.1
6	Mean	427	479	515	563
6	PR<PL	69.3	54.3	42.9	17.1
6	PR>PL	26.4	42.1	52.1	79.3
3	Mean	346	415	502	511
3	PR<PL	45.0	12.9	14.3	12.9
3	PR>PL	46.4	85.0	83.5	85.0

Left-handed Subjects (front face)

R	L 3 PR>PL	L 3 PR<PL	L 3 Mean	L 6 PR>PL	L 6 PR<PL	L 6 Mean	L 9 PR>PL	L 9 PR<PL	L 9 Mean	L 12 PR>PL	L 12 PR<PL	L 12 Mean
3	70.0	21.4	327	47.1	50.7	457	20.7	75.0	457	42.9	53.6	519
6	85.7	11.4	426	68.6	27.1	473	50.0	47.9	543	46.4	51.4	545
9	84.3	11.4	472	65.7	30.0	504	60.0	36.4	590	59.3	37.1	593
12	80.7	17.1	553	80.0	16.4	579	72.9	23.6	592	62.1	36.4	644

Note: Mean in ms
Frequency in %

Table C3 continued

A=90°, S=2"

Combine

R		L 3	L 6	L 9	L 12
12	Mean	551.19	565.77	547.28	559.30
12	PR<PL	10.00	12.51	23.20	35.00
12	PR>PL	88.20	85.70	75.00	60.00
9	Mean	492.71	466.79	484.18	542.45
9	PR<PL	3.57	11.05	38.55	49.25
9	PR>PL	94.65	86.8	55.00	47.15
6	Mean	420.55	413.58	491.56	540.50
6	PR<PL	7.85	34.30	59.30	75.00
6	PR>PL	89.65	59.65	37.15	22.85
3	Mean	326.49	419.93	494.54	520.51
3	PR<PL	46.45	73.20	71.40	80.00
3	PR>PL	46.45	20.70	24.25	17.15

Left-handed Subjects

R	L 3 PR>PL	L 3 PR<PL	L 3 Mean	L 6 PR>PL	L 6 PR<PL	L 6 Mean	L 9 PR>PL	L 9 PR<PL	L 9 Mean	L 12 PR>PL	L 12 PR<PL	L 12 Mean
3	48.6	43.6	324	25.7	66.4	407	34.4	62.1	475	20.7	74.3	493
6	87.9	9.29	416	44.3	47.9	388	56.4	39.3	508	29.3	67.1	514
9	95.0	2.14	502	87.9	10.7	448	50.7	30.7	469	49.3	47.1	522
12	95.0	4.29	563	92.1	5.71	560	76.4	21.4	542	65.0	31.4	515

Right-handed Subjects

R	L 12 Mean	L 12 PR<PL	L 12 PR>PL	L 9 Mean	L 9 PR<PL	L 9 PR>PL	L 6 Mean	L 6 PR<PL	L 6 PR>PL	L 3 Mean	L 3 PR<PL	L 3 PR>PL
3	547	85.7	13.6	513	80.7	17.1	432	80.0	15.7	328	49.3	44.3
6	566	82.9	16.4	474	79.3	17.9	439	20.7	75.0	425	6.4	91.4
9	562	51.4	45.0	499	46.4	49.3	485	11.4	85.7	483	5	94.3
12	603	38.6	55.0	551	25.0	73.6	570	19.3	79.3	539	15.7	81.4

Table C3 continued

A=45°, S=10"

Left-handed Subjects

R	L=3 PR>PL	L=3 PR<PL	L=3 Mean	L=6 PR>PL	L=6 PR<PL	L=6 Mean	L=9 PR>PL	L=9 PR<PL	L=9 Mean	L=12 PR>PL	L=12 PR<PL	L=12 Mean
3	52.1	42.9	382	47.9	47.1	481	31.4	65.7	499	50.0	46.4	565
6	77.1	20.0	485	66.4	29.3	520	52.1	46.4	584	54.3	42.3	628
9	87.9	11.4	496	74.3	22.9	602	47.9	48.6	623	69.3	27.9	659
12	74.3	22.9	562	65.7	28.6	613	74.3	24.3	656	59.3	37.9	672

Combine

R		L=3	L=6	L=9	L=12
12	Mean	567.48	602.88	673.46	711.58
12	PR<PL	23.95	22.15	26.45	40.40
12	PR>PL	72.85	71.80	72.15	56.45
9	Mean	520.97	599.82	629.00	664.82
9	PR<PL	15.70	27.90	48.25	41.10
9	PR>PL	81.80	68.20	48.60	57.15
6	Mean	474.53	535.65	582.99	620.50
6	PR<PL	21.45	37.50	45.70	55.45
6	PR>PL	76.40	58.55	52.10	41.10
3	Mean	379.35	498.11	514.06	576.80
3	PR<PL	38.95	48.20	59.65	56.75
3	PR>PL	55.35	45.40	38.55	41.05

Right-handed Subjects

L		R=3	R=6	R=9	R=12
12	Mean	588	612	669	750
12	ρR<ρL	67.1	68.6	54.3	42.9
12	ρR>ρL	32.1	27.9	45.0	53.6
9	Mean	528	581	634	590
9	ρR<ρL	53.6	45.0	47.9	28.6
9	ρR>ρL	45.7	52.1	49.3	70.0
6	Mean	514	551	597	592
6	ρR<ρL	49.3	45.7	32.9	15.7
6	ρR>ρL	42.9	50.7	62.1	77.9
3	Mean	376	463	545	572
3	ρR<ρL	35.0	22.9	20.0	25.0
3	ρR>ρL	59.6	75.7	75.7	71.4

Table C3 continued

A=90°, S=10"

Combine

R		L 3	L 6	L 9	L 12
12	Mean	578.61	591.28	602.78	618.75
12	PR<PL	7.85	8.24	22.15	35.70
12	PR>PL	89.65	89.65	73.55	61.40
9	Mean	529.41	528.87	577.32	581.87
9	PR<PL	7.15	14.65	33.95	62.85
9	PR>PL	91.45	82.9	62.85	32.85
6	Mean	466.88	473.89	552.03	586.67
6	PR<PL	4.67	39.65	58.55	59.30
6	PR>PL	94.65	53 2	37.5	36.80
3	Mean	382.21	459.47	516.25	570.05
3	PR<PL	39.20	70.75	75.00	69.65
3	PR>PL	52.85	23.55	23.20	28.25

Right-handed Subjects

R	L 12 Mean	L 12 PR<PL	L 12 PR>PL	L 9 Mean	L 9 PR<PL	L 9 PR>PL	L 6 Mean	L 6 PR<PL	L 6 PR>PL	L 3 Mean	L 3 PR<PL	L 3 PR>PL
3	587	80.7	17.9	520	88.6	9.3	463	83.6	11.4	379	40.0	51.4
6	607	73.6	22.9	559	650	32.1	490	40.0	55.0	463	7.9	91.4
9	617	75.0	21.4	607	45.0	53.6	536	15.0	82.9	519	8.9	88.6
12	632	46.4	52.1	587	24.3	71.4	590	12.9	84.3	585	6.4	90.7

Left-handed Subjects

R	L 3 PR>PL	L 3 PR<PL	L 3 Mean	L 6 PR>PL	L 6 PR<PL	L 6 Mean	L 9 PR>PL	L 9 PR<PL	L 9 Mean	L 12 PR>PL	L 12 PR<PL	L 12 Mean
3	54.3	38.6	385	35.7	57.9	455	37.1	61.4	511	38.6	58.6	553
6	97.9	14 3	470	51.4	39.3	457	42.9	52.1	544	50.7	45.0	565
9	94.3	5.7	539	82.9	14.3	521	72.1	22.9	547	44.3	50.7	546
12	88.6	9.3	571	95.0	35.7	591	75.1	20.0	617	70.7	25.0	613

Experimental design model: randomized mixed-nested factorial design

Main Effects	Symbol	Level	Type
Distances traveled	B_j	4	Fixed
Starting separation distance	S_k	2	Fixed
Angle of reach	A_l	2	Fixed
Handedness of subjects	H_m	2	Fixed
subject	$O_{p(m)}$	7	Random
Residual	$E_{n(jklmp)}$	20	Random

Table C4: EMS Table - SYM-SIMO

$EMS = a\sigma_e^2 + b\sigma_x^2 + c\phi_y$

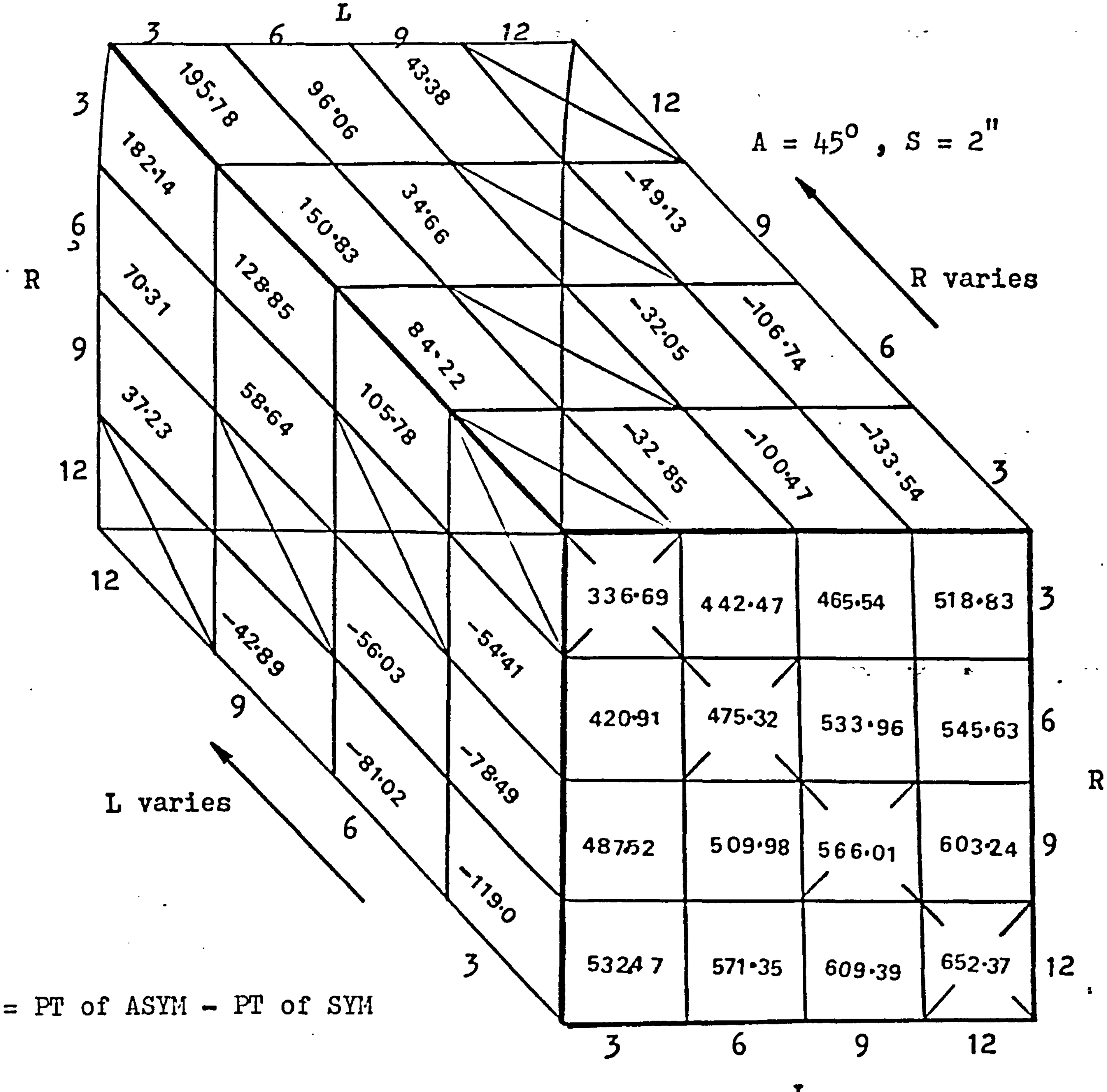
Source	B	S	A	H	O	R_n	a	b	x	c	y
B_j	0	2	2	2	7	20	1	80	BO	1120	B
S_k	4	0	2	2	7	20	1	160	SO	2240	S
A_l	4	2	0	2	7	20	1	160	AO	2240	A
H_m	4	2	2	0	7	20	1	320	O	2240	H
$O_{p(m)}$	4	2	2	1	1	20	1	320	O		
$(B*S)_{jk}$	0	0	2	2	7	20	1	40	BSO	560	BS
$(B*A)_{jl}$	0	2	0	2	7	20	1	40	BAO	560	BA
$(B*H)_{jm}$	0	2	2	0	7	20	1	80	BO	560	BH
$(B*O)_{jp(m)}$	0	2	2	1	1	20	1	80	BO		
$(S*A)_{kl}$	4	0	0	2	7	20	1	80	SAO	1120	SA
$(S*H)_{km}$	4	0	2	0	7	20	1	160	SO	1120	SH
$(S*O)_{kp(m)}$	4	0	2	1	1	20	1	160	SO		
$(A*H)_{lm}$	4	2	0	0	7	20	1	160	AO	1120	AH
$(A*O)_{lp(m)}$	4	2	0	1	1	20	1	160	AO		
$(B*S*A)_{jkl}$	0	0	0	2	7	20	1	20	BSAO	280	BSA
$(B*S*H)_{jkm}$	0	0	2	0	7	20	1	40	BSO	280	BSH
$(B*S*O)_{jkp(m)}$	0	0	2	1	1	20	1	40	BSO		

Table C4 : EMS Table - SYM-SIMO

$EMS = a\sigma_e^2 + b\sigma_x^2 + c\phi_y$

Source	B	S	A	H	O	R_n	a	b	x	c	y
$(B*A*H)_{jlm}$	0	2	0	0	7	20	1	40	BAO	280	BAH
$(B*A*O)_{jlp(m)}$	0	2	0	1	1	20	1	40	BAO		
$(S*A*H)_{klm}$	4	0	0	0	7	20	1	80	SAO	560	SAH
$(S*A*O)_{klp(m)}$	4	0	0	1	1	20	1	80	SAO		
$(B*S*A*H)_{jklm}$	0	0	0	0	1	20	1	20	BSAO	140	BSAH
$(B*S*A*O)_{jklp(m)}$	0	0	0	1	1	20	1	20	BSAO		
$E_{n(jklmp)}$	1	1	1	1	1	1	1				

Table C4 continued



Note:
PT Difference = PT of ASYM - PT of SYM

Table C5 : Performance Time Comparison between SYM-SIMO and ASYM-SIMO

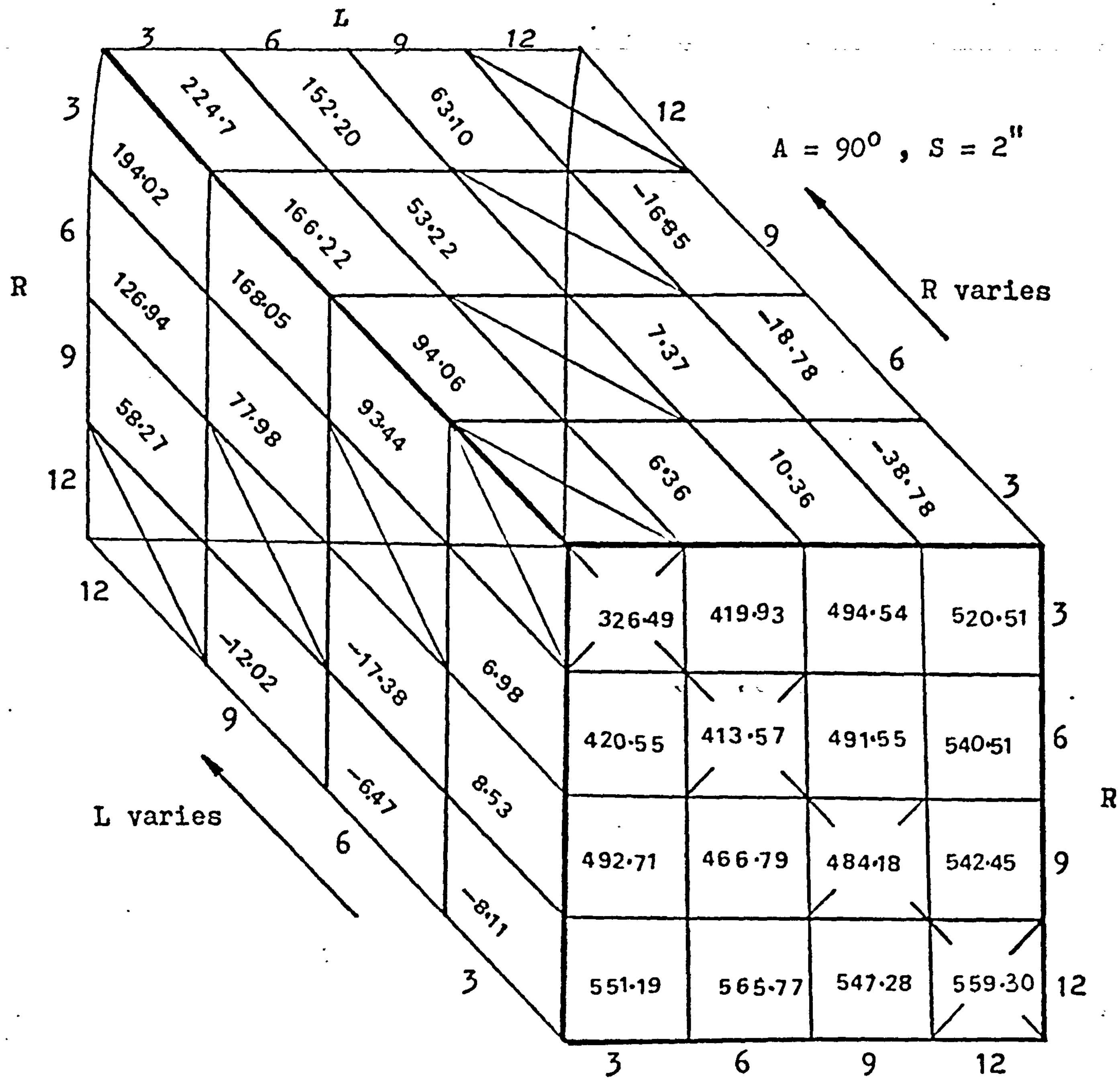


Table C5 continued

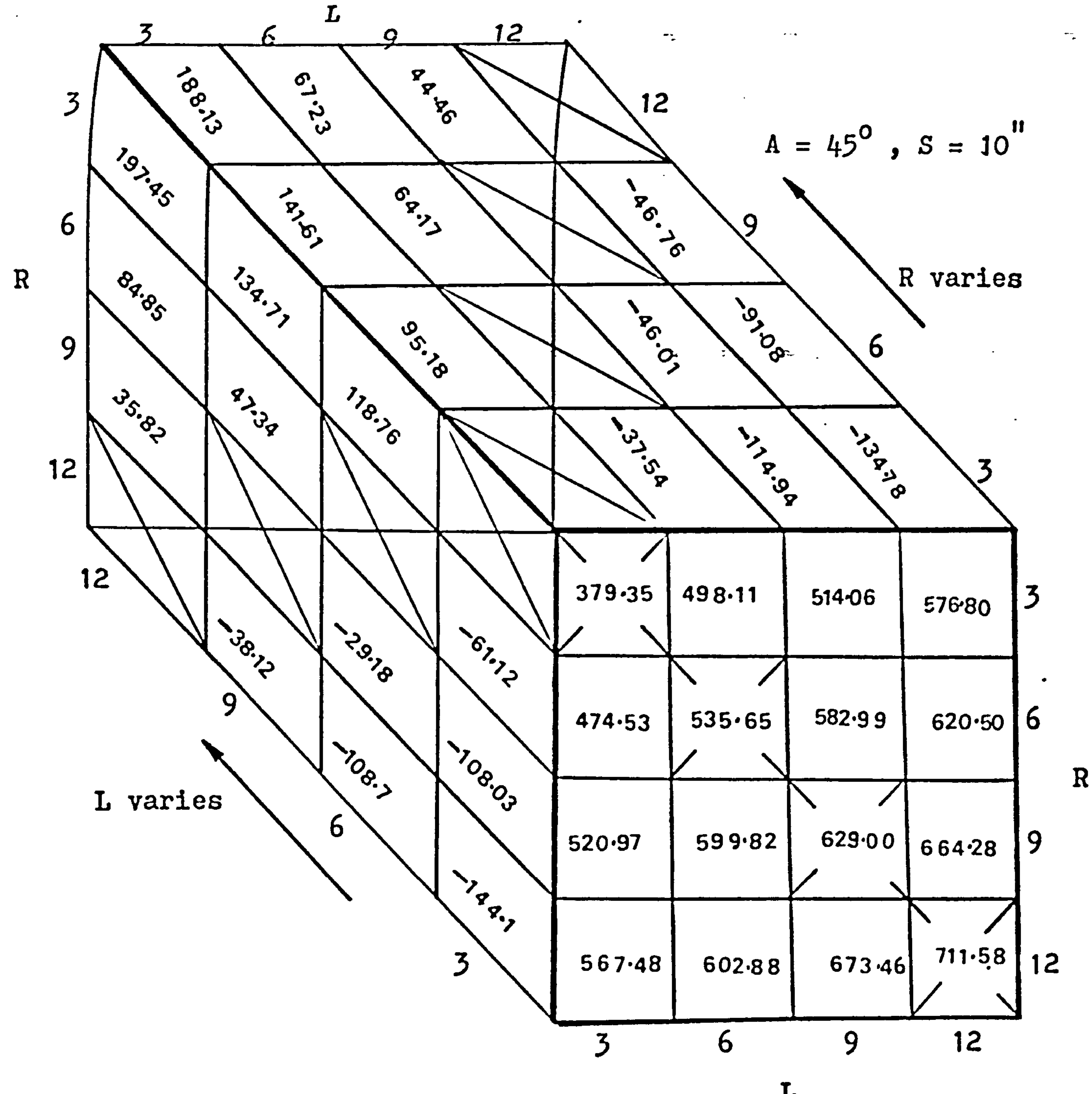


Table C5 continued

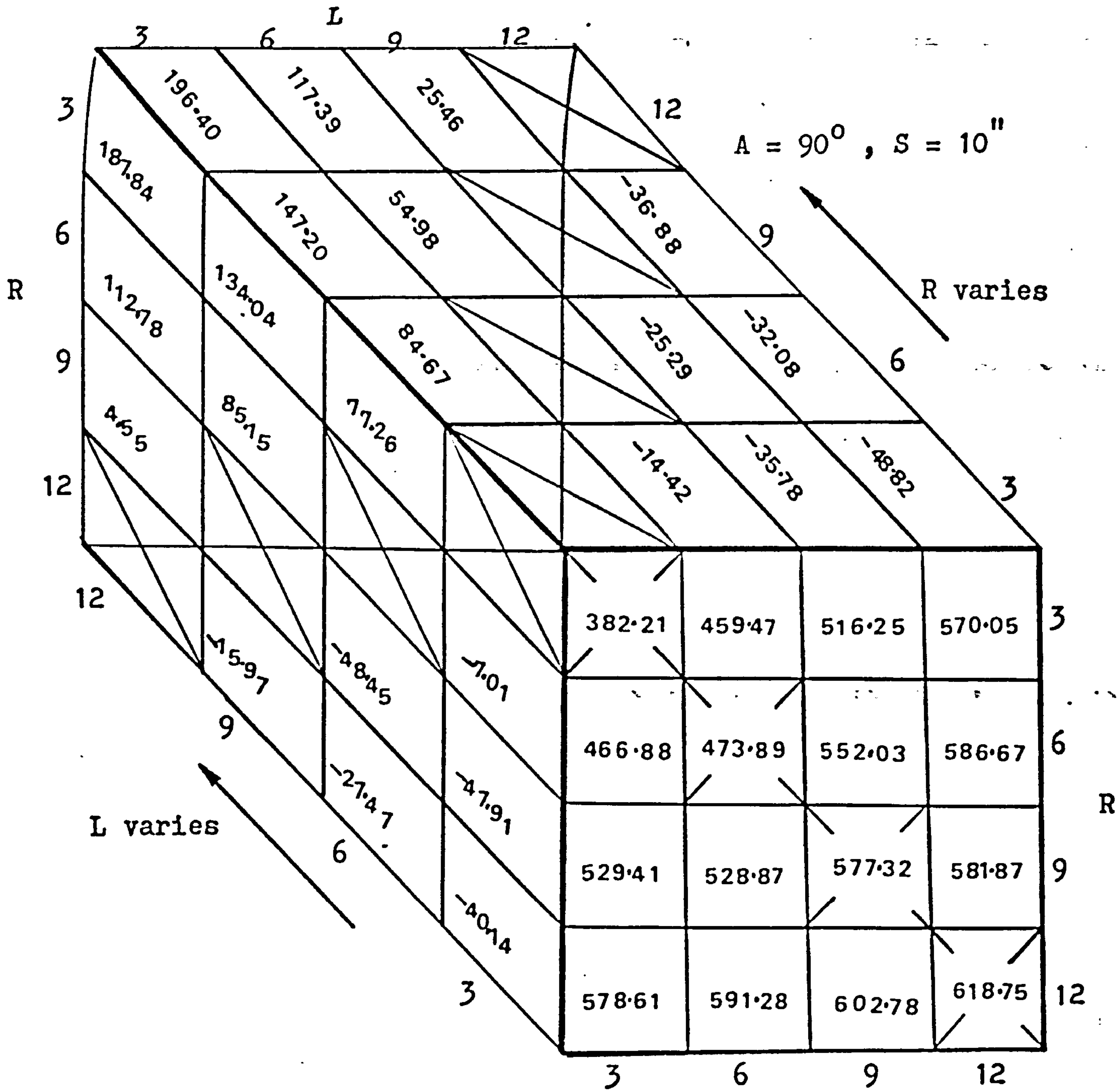


Table C5 continued

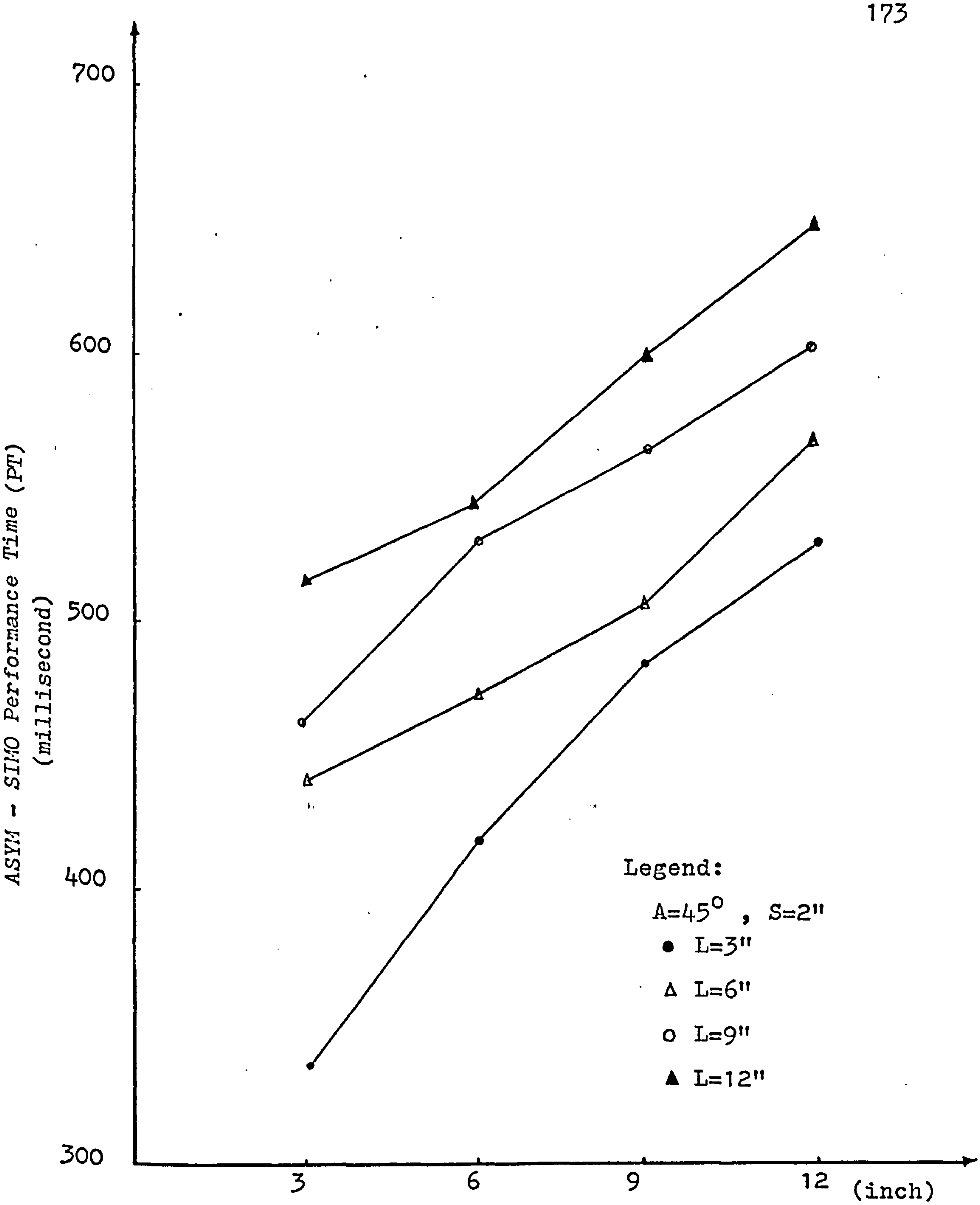


Figure C1. PT vs R with A=45°, S=2"

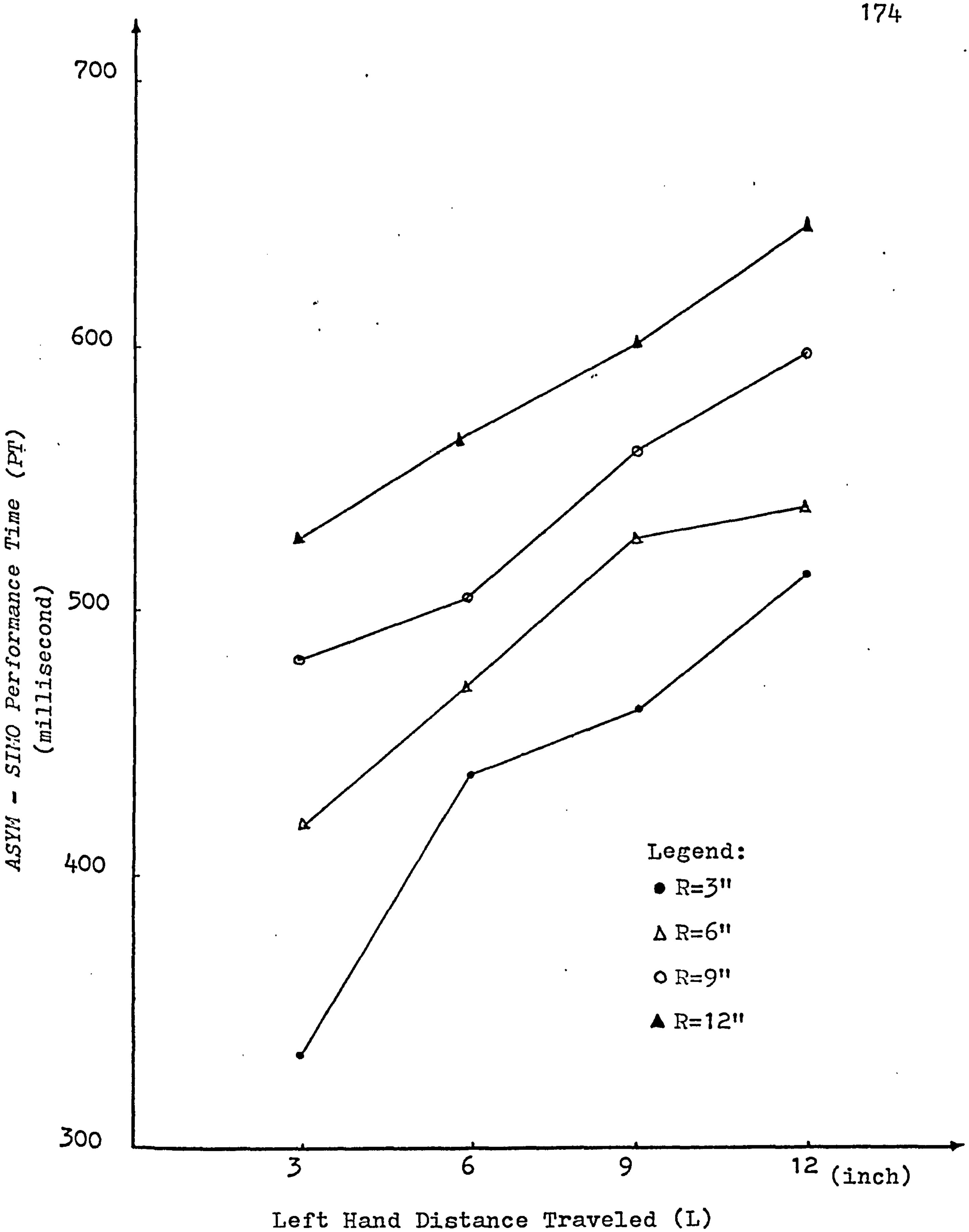


Figure C2. PT vs L with A=45°, S=2"

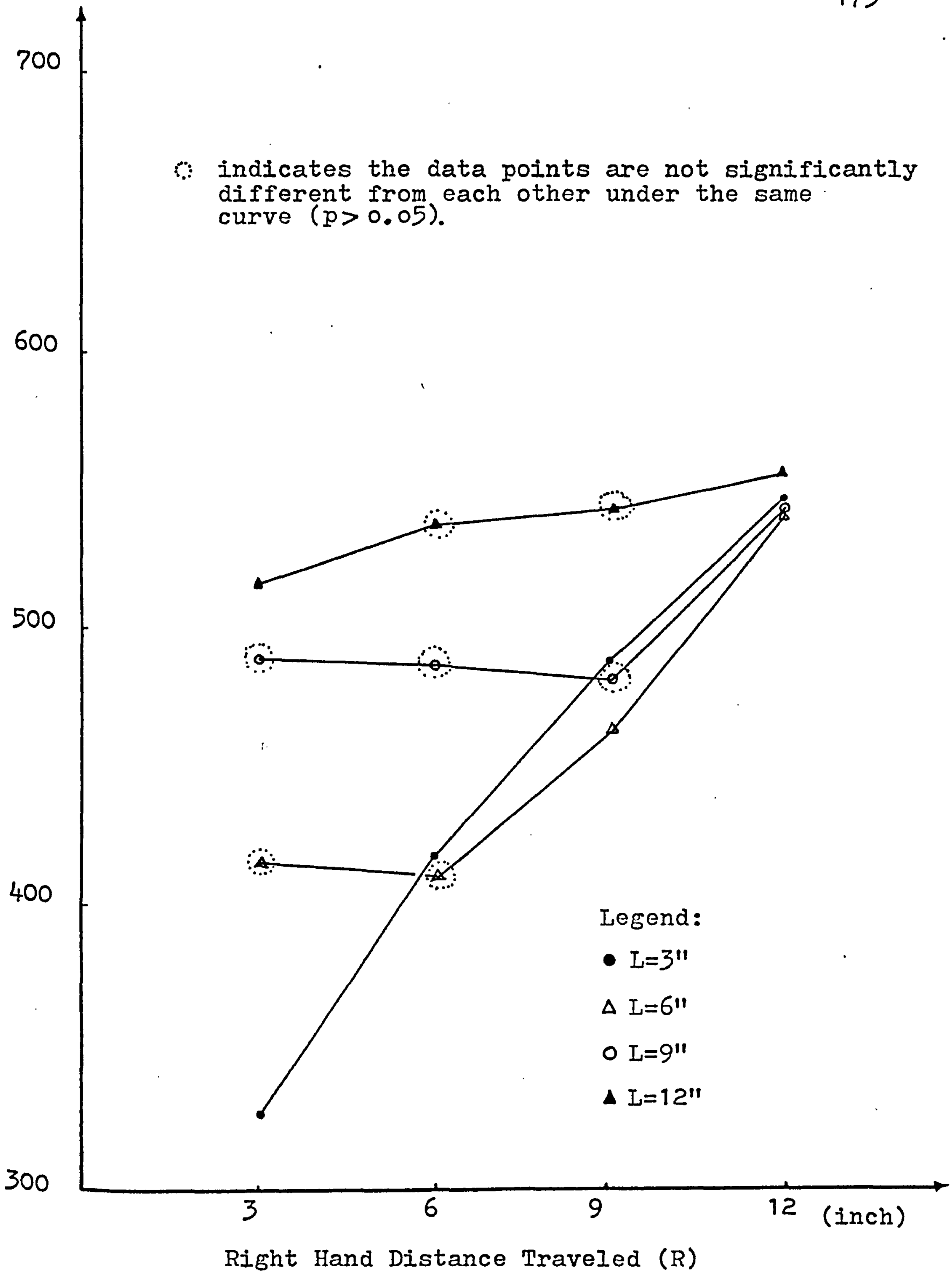


Figure C3. PT vs R with A=90° , S=2"

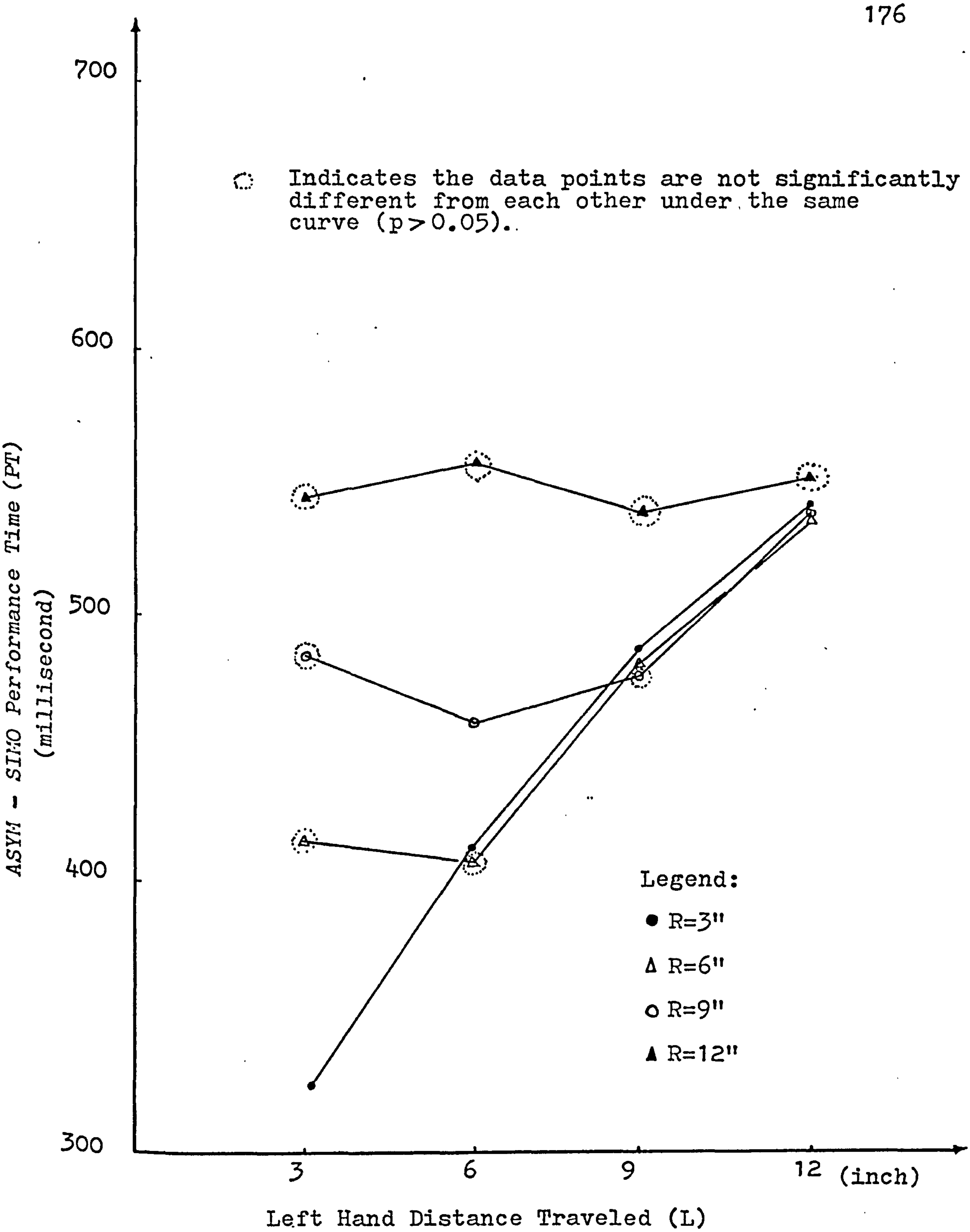


Figure C4. PT vs L with A=90^{o} , S=2"

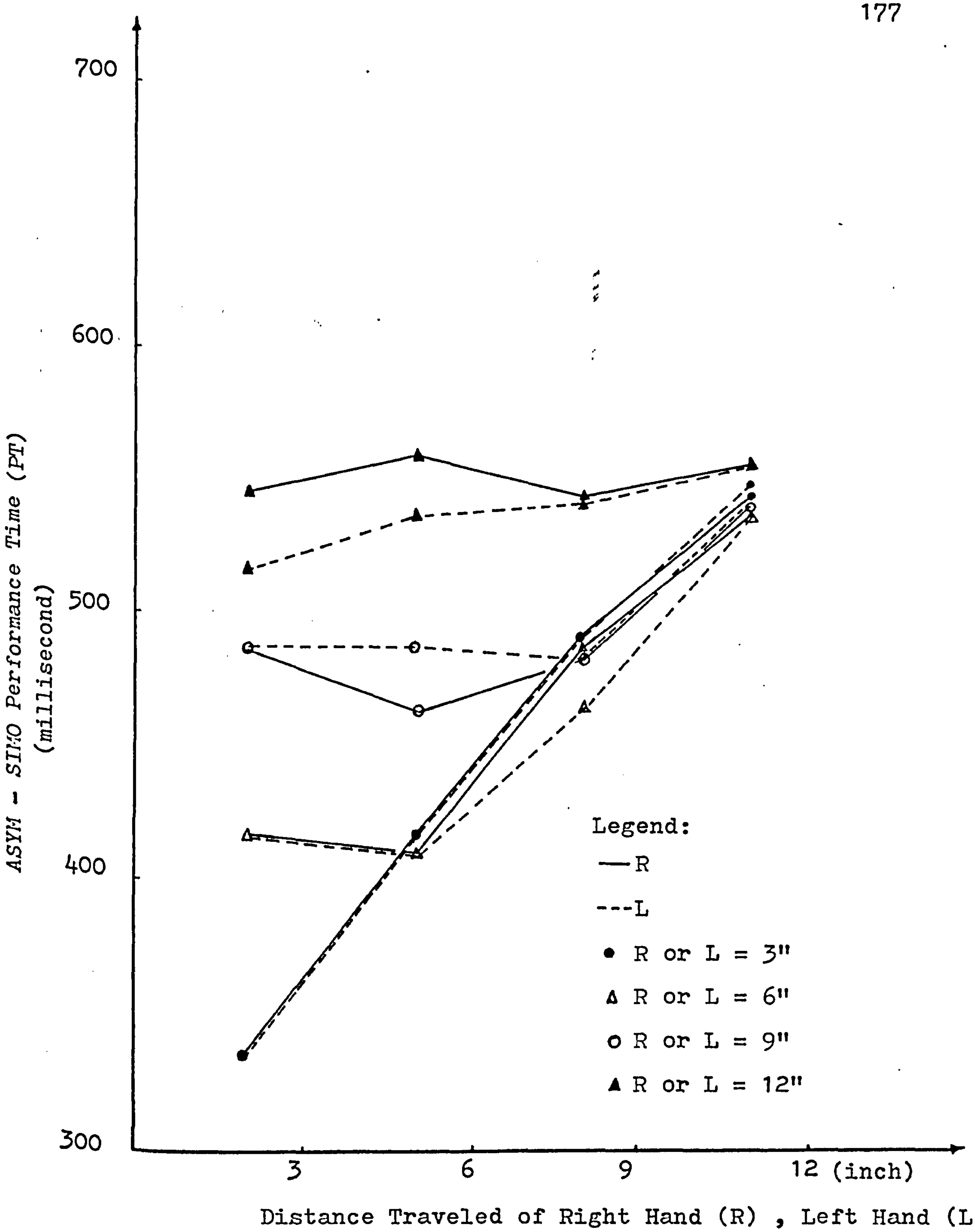
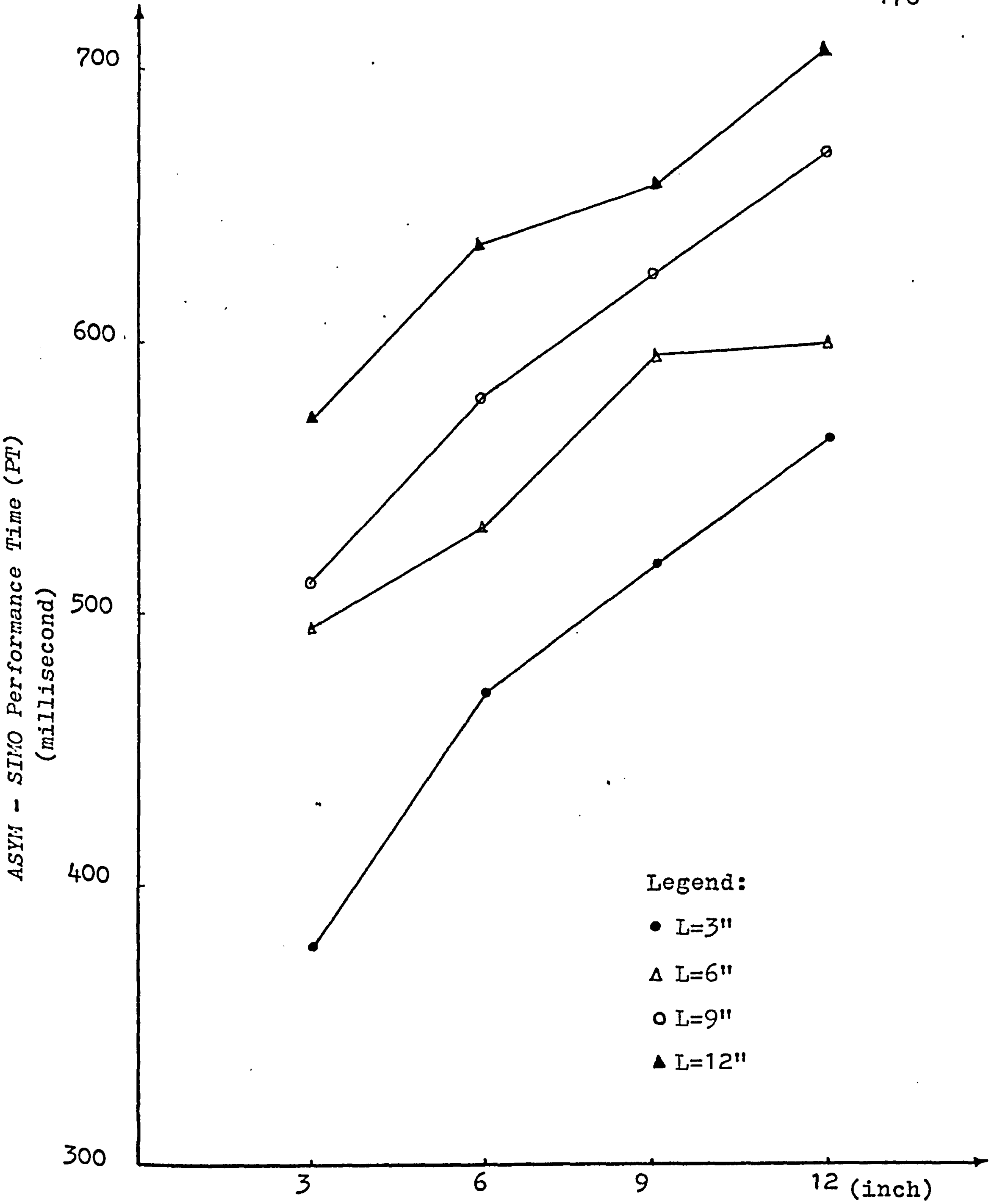


Figure C5. PT vs R, L with $A=90^{\circ}$, S=2"



Right Hand Distance Traveled (R)

Figure C6. PT vs R with A=45° , S=10"

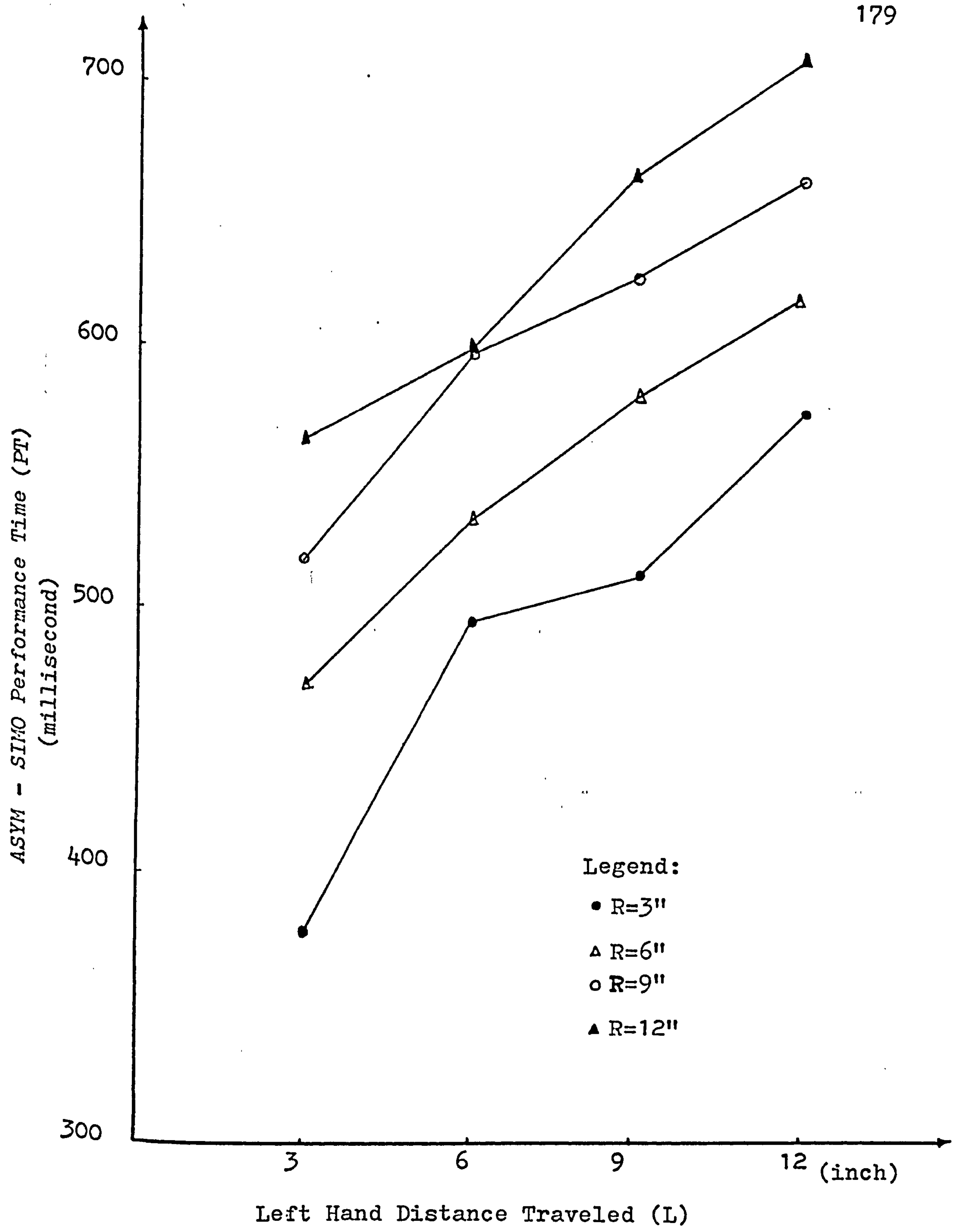


Figure C7. PT vs L with A=45°, S=10"

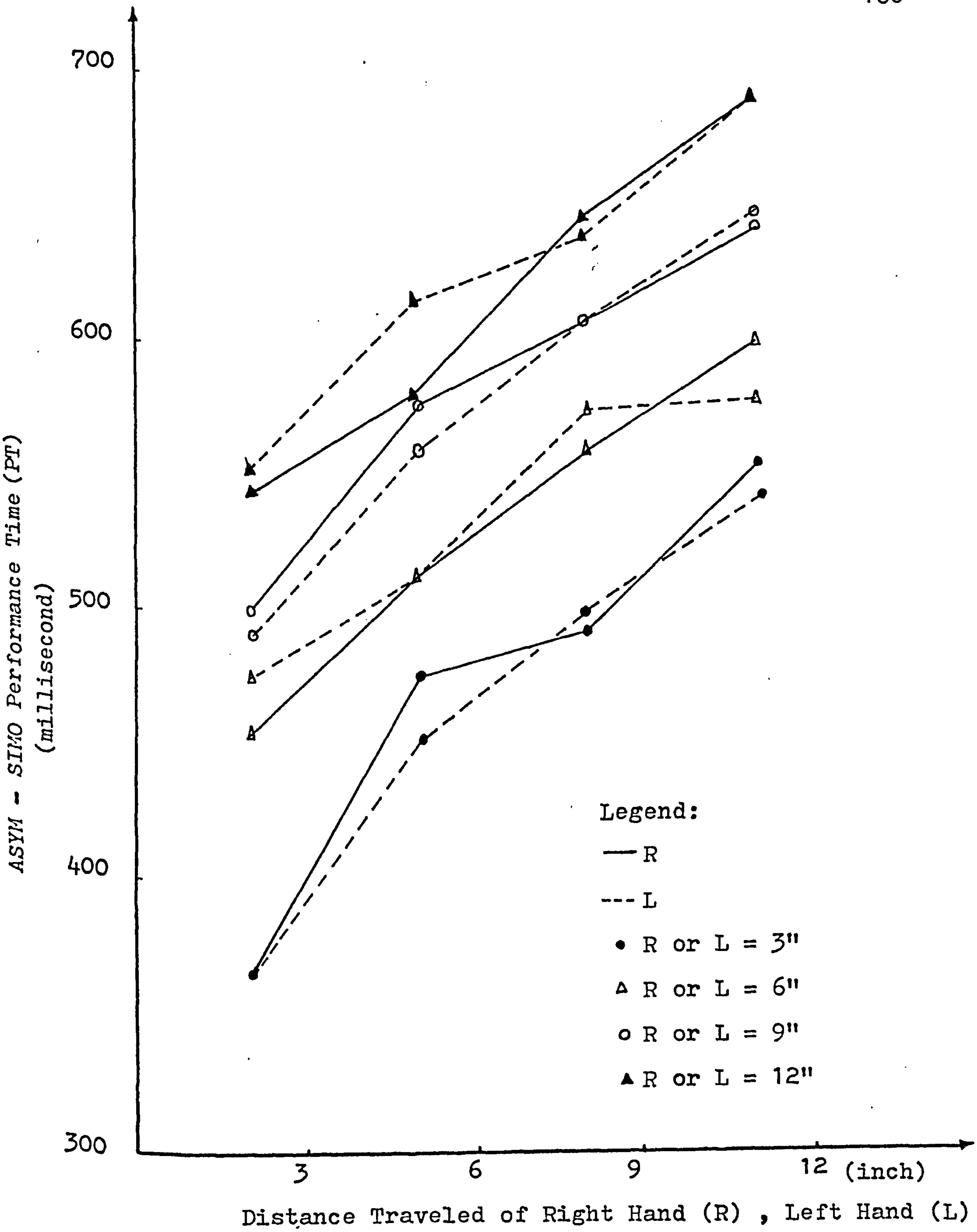


Figure C8. PT vs R , L with A=45° , S=10"

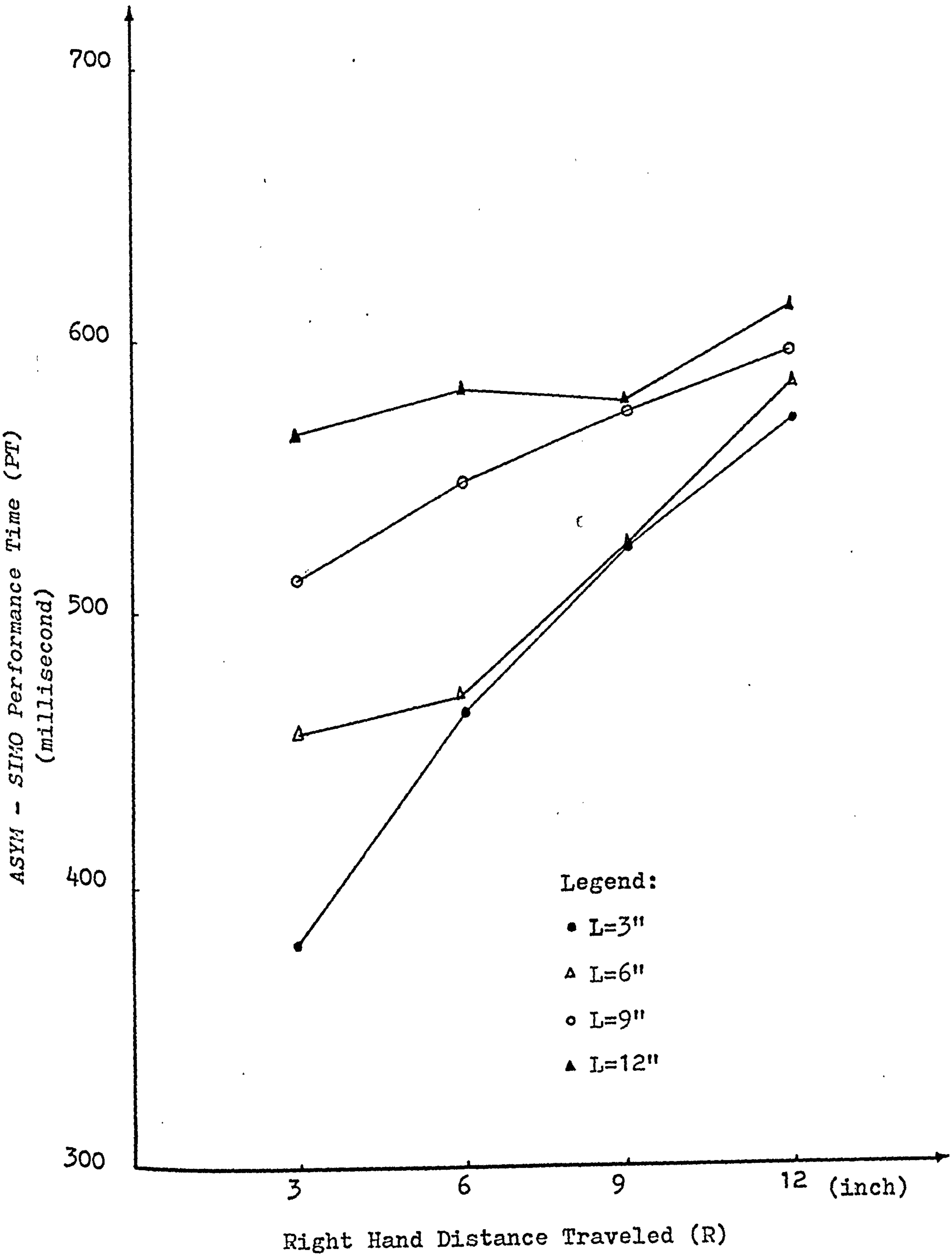


Figure C9. PT vs R with A=90°, S=10"

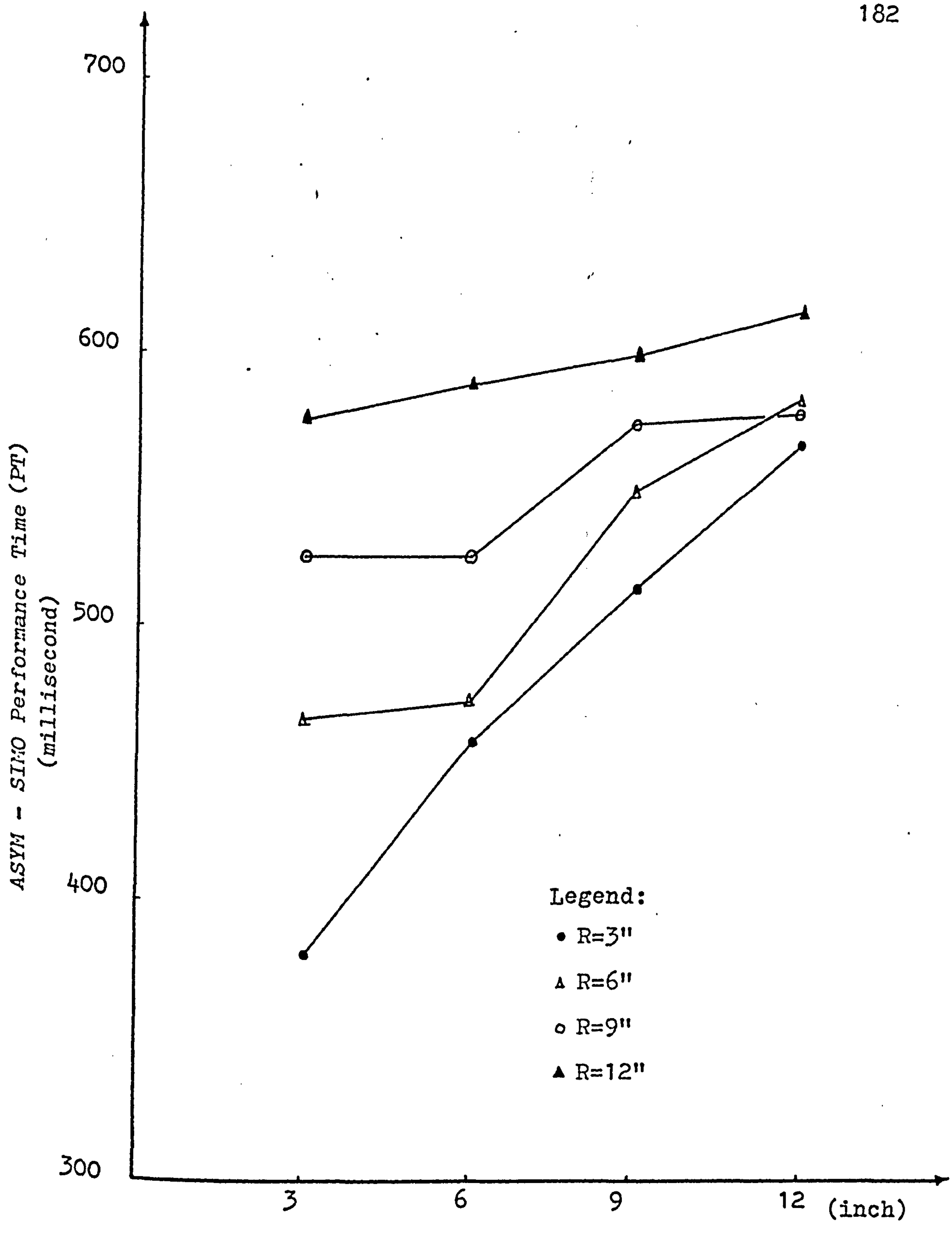


Figure C10. PT vs L with A=90° , S=10"

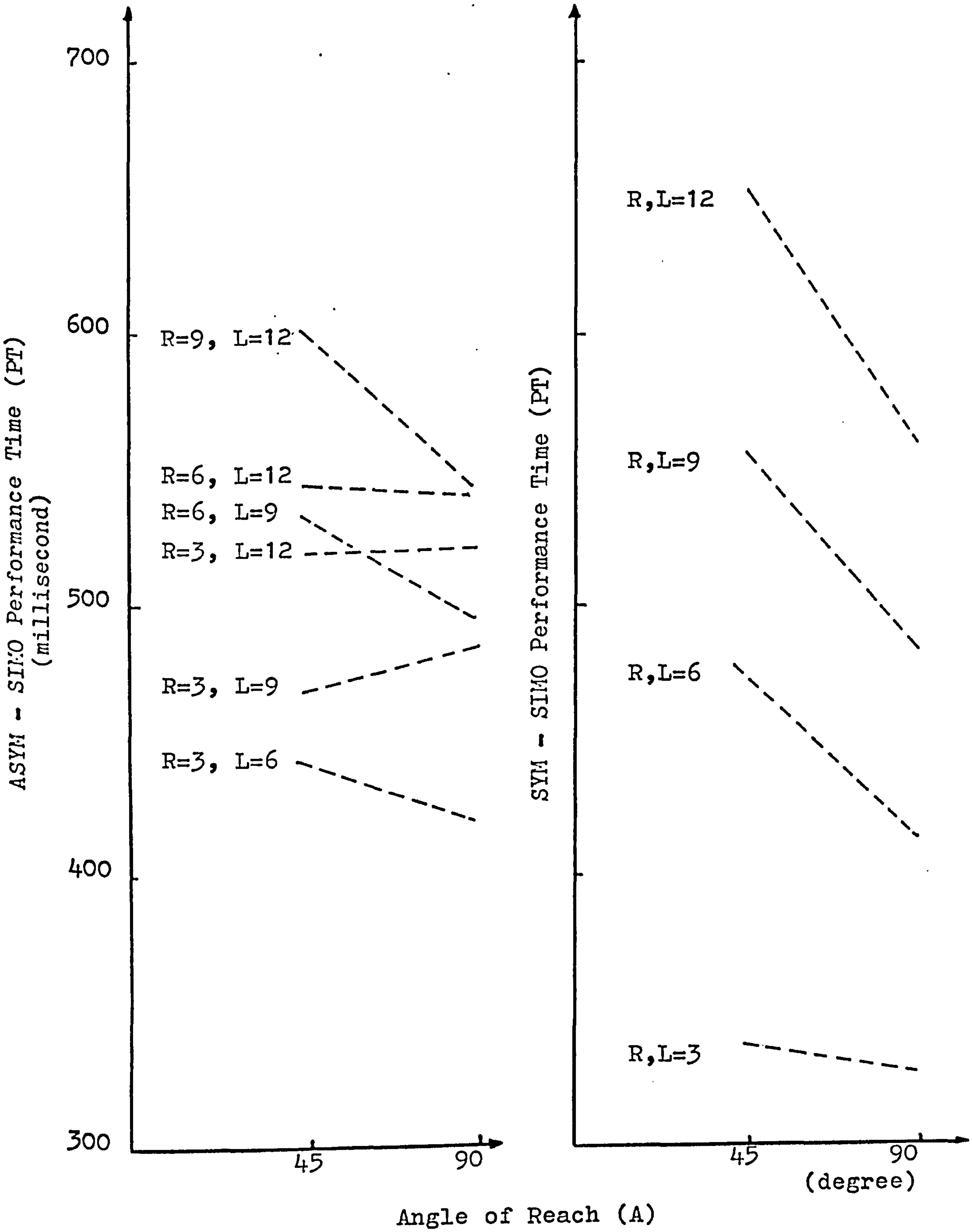


Figure C11. PT vs A with S=2" for SYM- and ASYM-SIMO

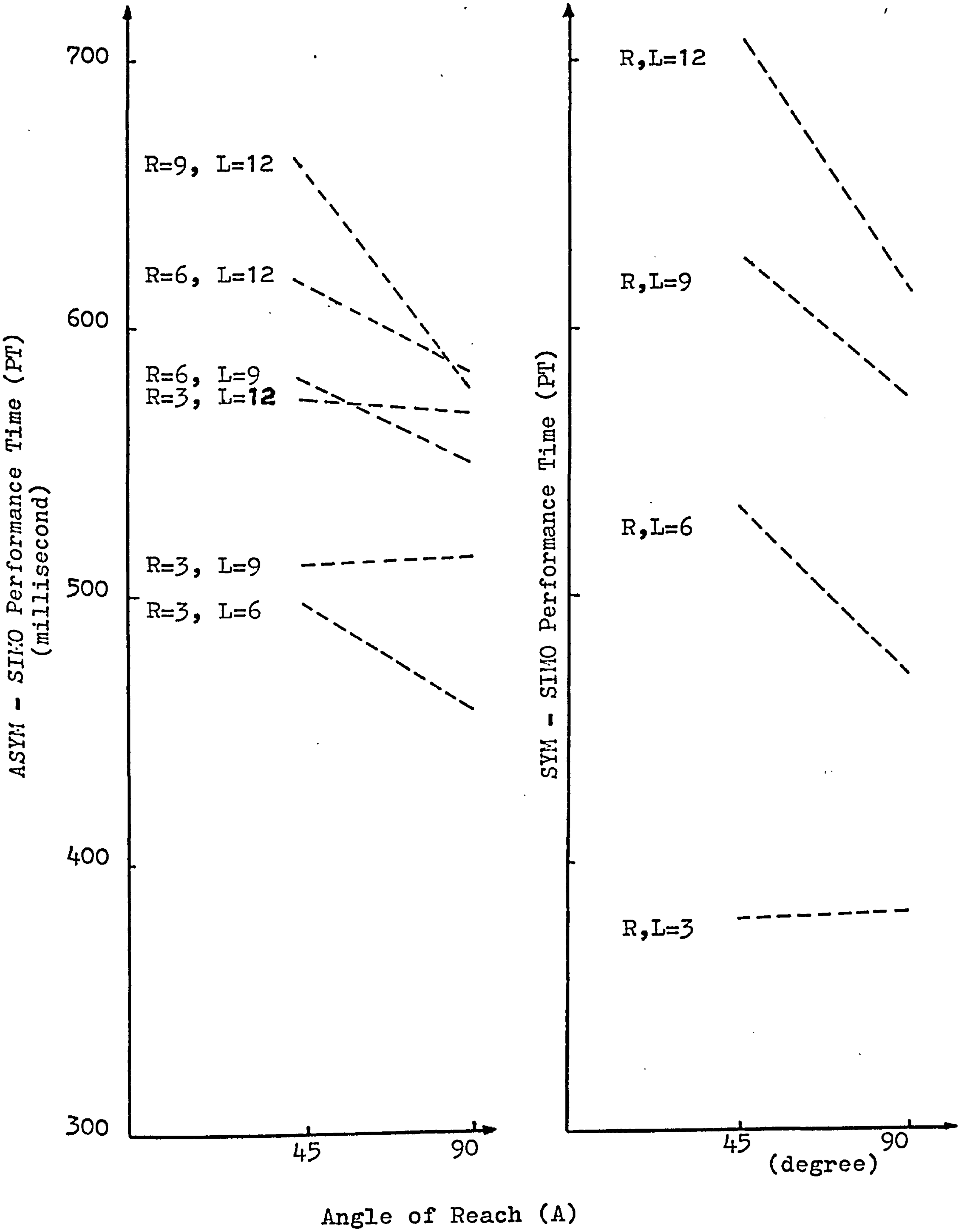


Figure C12. PT vs A with S=10" for SYM- and ASYM-SIMO

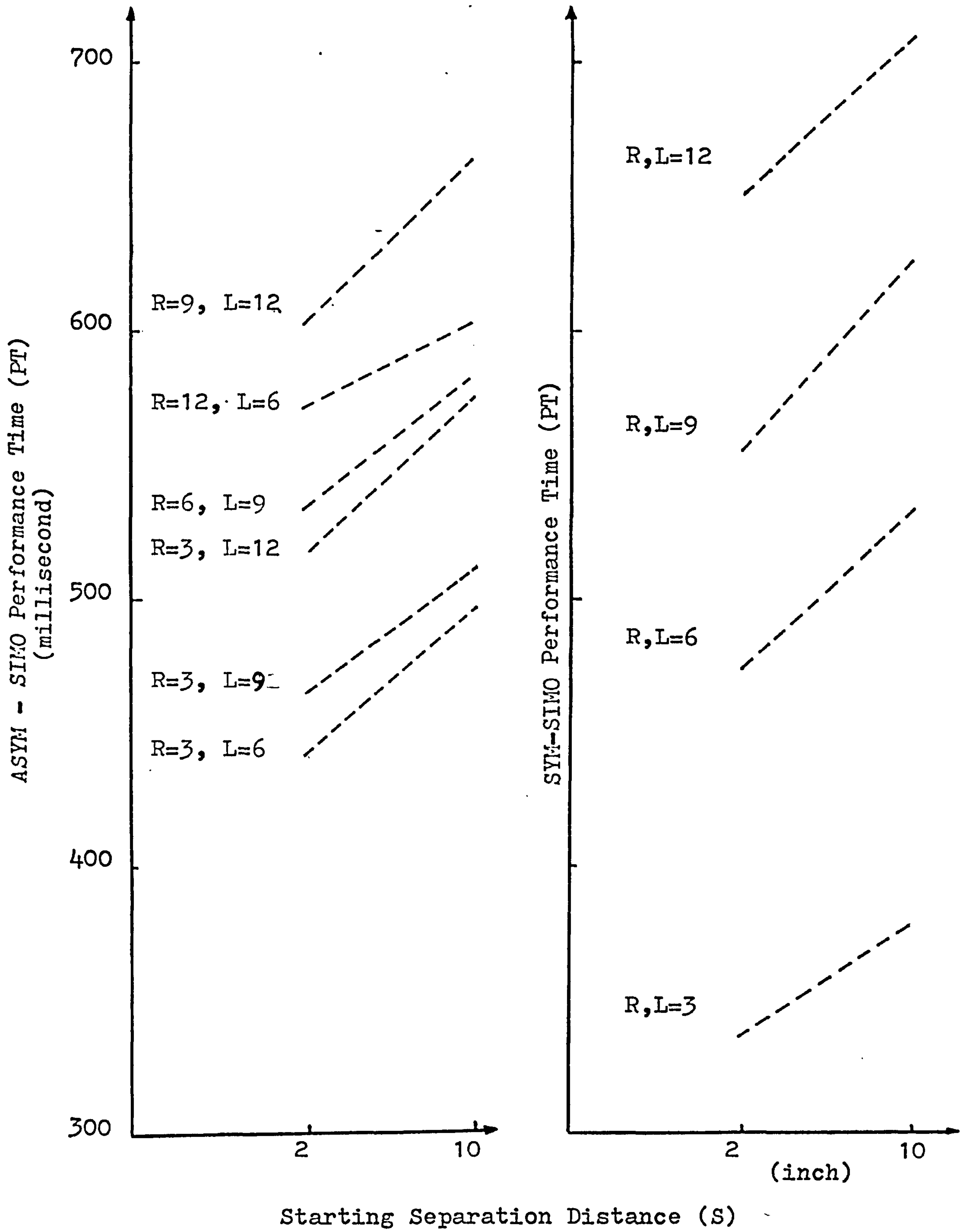
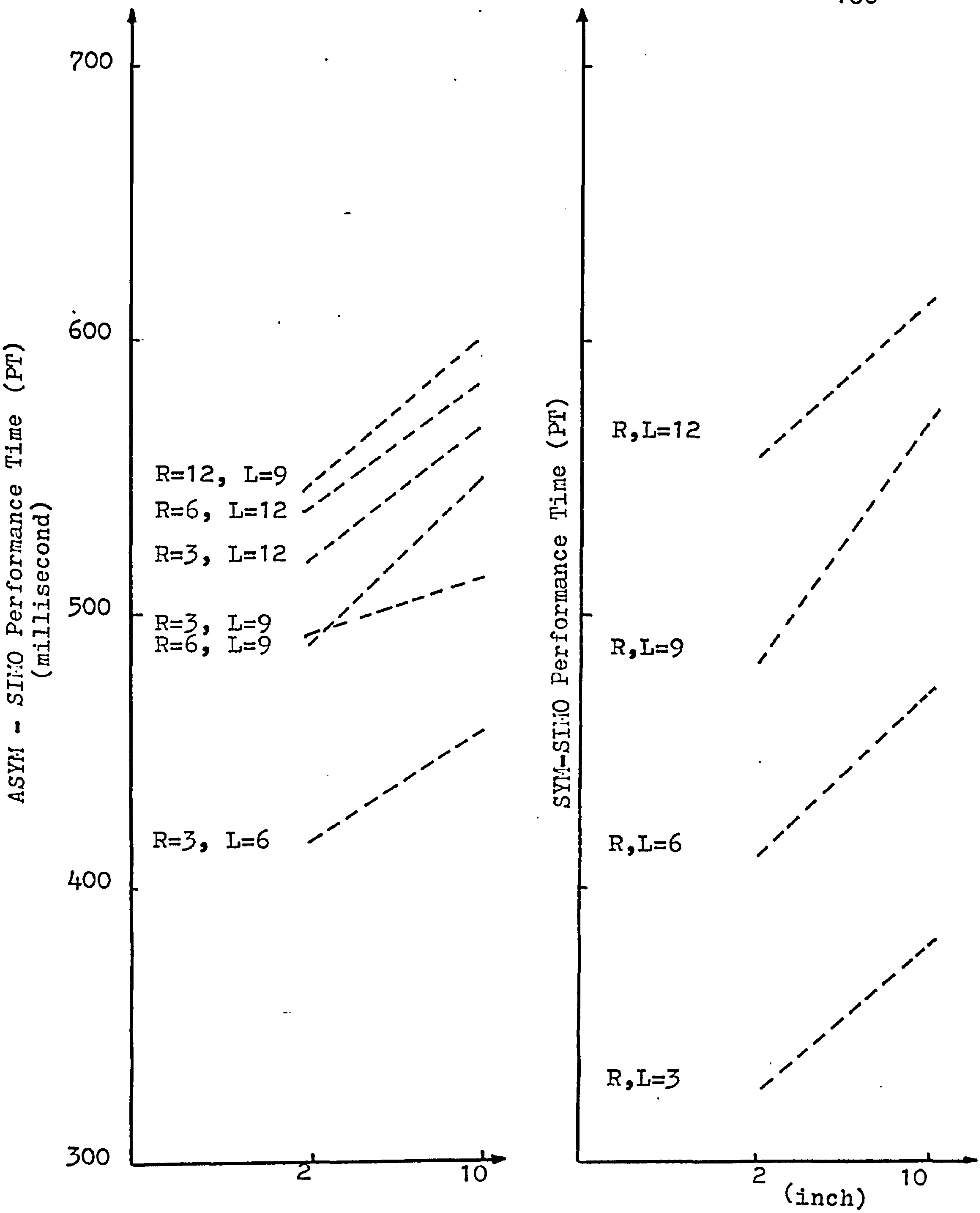


Figure C13. PT vs S with A=45° for SYM- and ASYM-SIMO



Starting Separation Distance (S)

Figure C14. PT vs S with A=90° for SYM- and ASYM-SIMO

APPENDIX C.1

COMPUTER PROGRAM FOR INPUT DATA INTO MAGNETIC TAPE STORAGE - STUDY #2

```
NOTE: THE JOB MAK HAS BEEN RUN UNDER RELEASE 75.6 OF SAS AT THE UNIVERSITY OF WINDSOR.

1               DATA MAIN;
2       LOOP1:  INPUT H 74 SUBJ 75-76 COND 77-80 @;
3               RETAIN HAND CONDND SUBJNO ;;
4               IF H=. THEN GO TO LOOP2;
5               HAND=H;
6               CONDND=COND;
7               SUBJNO=SUBJ;
8               INPUT / (P1-P18) (@2 18*4.);
9               GO TO LOOP3;
10      LOOP2:  INPUT (P1-P18) (@2 18*4.) ;
11      LOOP3:  DROP P1-P18;
12              IF P1=0 OR P2=0 THEN GO TO LOOP4;
13              IF P1=. OR P2=. THEN DELETE;
14              PR=P1*3; PL=P2*3; PT=MAX(PR,PL); OUTPUT;
15      LOOP4:  IF P3=0 OR P4=0 THEN GO TO LOOP5;
16              IF P3=. OR P4=. THEN DELETE;
17              PR=P3*3; PL=P4*3; PT=MAX(PR,PL); OUTPUT;
18      LOOP5:  IF P5=0 OR P6=0 THEN GO TO LOOP6;
19              IF P5=. OR P6=. THEN DELETE;
20              PR=P5*3; PL=P6*3; PT=MAX(PR,PL); OUTPUT;
21      LOOP6:  IF P7=0 OR P8=0 THEN GO TO LOOP7;
22              IF P7=. OR P8=. THEN DELETE;
23              PR=P7*3; PL=P8*3; PT=MAX(PR,PL); OUTPUT;
24      LOOP7:  IF P9=0 OR P10=0 THEN GO TO LOOP8;
25              IF P9=. OR P10 =. THEN DELETE;
26              PR=P9*3; PL=P10*3; PT=MAX(PR,PL); OUTPUT;
27      LOOP8:  IF P11=0 OR P12=0 THEN GO TO LOOP9;
28              IF P11=. OR P12=. THEN DELETE;
29               PR=P11*3; PL=P12*3; PT=MAX(PR,PL); OUTPUT;
30      LOOP9:  IF P13=0 OR P14=0 THEN GO TO LOOP10;
31              IF P13=. OR P14=. THEN DELETE;
32               PR=P13*3; PL=P14*3; PT=MAX(PR,PL); OUTPUT;
33      LOOP10: IF P15=0 OR P16=0 THEN GO TO LOOP11;
34              IF P15=. OR P16=. THEN DELETE;
35               PR=P15*3; PL=P16*3; PT=MAX(PR,PL); OUTPUT;
36      LOOP11: IF P17=0 OR P18=0 THEN GO TO LOOP1;
37              IF P17=. OR P18=. THEN DELETE;
38               PR=P17*3; PL=P18*3; PT=MAX(PR,PL); OUTPUT;
39              KEEP HAND CONDND SUBJNO PR PL PT;
40              GO TO LOOP1;
41              CARDS;

NOTE: LOST CARD.

RULE:     1234567 101234567 201234567 301234567 401234567 501234567 601234567 701234567 80

6187       142 169 148 194 159 173 153 170 162 182 150 175 159 184 156 168 153 174
_ERROR_=1 _N_=780 H=. SUBJ=. COND=. HAND=2 CONDND=13 SUBJNO=17 P1=142 P2=159 P3=148 P4=194 P5=159 P6=173 P7=153 P8=170 P9=152
P10=182 P11=150 P12=175 P13=159 P14=184 P15=156 P16=168 P17=153 P18=174 PR=459 PL=522 PT=522
NOTE: DATA SET WORK.MAIN HAS 43669 OBSERVATIONS AND 6 VARIABLES. 140 OBS/TRK.
NOTE: THE DATA STATEMENT USED 50.26 SECONDS AND 102K.

6188            PROC SORT; BY SUBJNO CONDND;
6189

NOTE: SORT IS NOT SUPPORTED BY THE AUTHOR OR BY SAS.
NOTE: DATA SET WORK.MAIN HAS 43669 OBSERVATIONS AND 6 VARIABLES. 140 OBS/TRK.
NOTE: THE PROCEDURE SORT USED 50.39 SECONDS AND 106K.

6189            PROC MEANS DATA=MAIN NOPRINT;
6190            VARIABLES PR PL; BY SUBJNO CONDND;
6191            OUTPUT OUT=STATS MEAN=MR ML STD=STDR STDL N=NS;
6192

NOTE: DATA SET WORK.STATS HAS 896 OBSERVATIONS AND 7 VARIABLES. 121 OBS/TRK.
NOTE: THE PROCEDURE MEANS USED 40.73 SECONDS AND 116K.

6192            DATA MYTAPE.CRURF;
6193            MERGE MAIN STATS;
6194            BY SUBJNO CONDND;
6195            RETAIN R 1 L 1 A 1 S 1 RNL 4 LNL 4 ANL 2 SNL 2 N 1;
6196            PERORPR=MR+STDR;
6197            NERORPR=MR-2*STDR;
```

```
         PERORPL=ML+STDL;
         NERURPL=ML-2*STDL;
         IF FIRST.CONDNO=0 AND LAST.CONDNO=1 AND PR>PERORPR THEN GO TO L1;
         IF FIRST.CONDNO=0 AND LAST.CONDNO=1 AND PR<NERORPR THEN GO TO L1;
         IF FIRST.CONDNO=0 AND LAST.CONDNO=1 AND PL>PERORPL THEN GO TO L1;
         IF FIRST.CONDNO=0 AND LAST.CONDNO=1 AND PL<NERORPL THEN GO TO L1;
         IF PR>PERORPR THEN DELETE;
         IF PR<NERORPR THEN DELETE;
         IF PL>PERORPL THEN DELETE;
         IF PL<NERORPL THEN DELETE;
        R=R; L=L; A=A; S=S; OUTPUT;
        N=N+1;
         IF FIRST.CONDNO=0 AND LAST.CONDNO=1 THEN GO TO L1;
         RETURN;
    L1:  N=1;
         IF R< RNL THEN GO TO C1;
         IF R=RNL AND L< LNL THEN GO TO C2;
         IF R=RNL AND L=_N_ AND A<AN_ THEN GO TO C3;
         GO TO C4;
    C1: R=R+1;
         GO TO C5;
    C2: R=1; L=L+1;
         GO TO C5;
    C3: R=1; L=1; A=A+1;
         GO TO C5;
    C4: R=1; L=1; A=1; S=S+1;
         IF S<=SNL THEN GO TO C5;
         R=1; L=1; A=1; S=1;
         DROP RNL LNL ANL SNL;
    C5:  IF PR>PERORPR THEN DELETE;
         IF PR<NERORPR THEN DELETE;
         IF PL>PERORPL THEN DELETE;
         IF PL<NERORPL THEN DELETE;
         RETURN;
```

APPENDIX C.2

ANOVA - STUDY #2

```
S T A T I S T I C A L   A N A L Y S I S   S Y S T E M        22:23 TUESDAY, MAY 23, 1978  897

                    ANALYSIS OF VARIANCE PROCEDURE
                       CLASS LEVEL INFORMATION

                 CLASS      LEVELS     VALUES
                 SUBJNO        7       1 2 3 4 5 6 7
                 R             4       1 2 3 4
                 L             4       1 2 3 4
                 A             2       1 2
                 S             2       1 2
                 HAND          2       1 2

              NUMBER OF OBSERVATIONS IN DATA SET = 17920
```

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: PT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	895	211410492.94276237	236212.84127683	278.99	0.0001	0.936173	5.4975
ERROR	17024	14413714.20009518	846.67024202		STD DEV		PT MEAN
CORRECTED TOTAL	17919	225824207.14285755			29.09759856		529.28571429

SOURCE	DF	ANOVA SS	F VALUE	PR > F
HAND	1	747298.06272316	882.63	0.0001
SUBJNO(HAND)	12	63678668.59888172	6267.56	0.0001
R	3	42716476.43437481	16817.44	0.0001
R*HAND	3	76143.63504410	30.77	0.0001
SUBJNO*R(HAND)	36	3364000.94932842	110.37	0.0001
L	3	37258363.26562500	14668.59	0.0001
L*HAND	3	669864.87522221	263.73	0.0001
SUBJNO*L(HAND)	36	2498083.45915031	81.96	0.0001
R*L	9	5476046.84999943	718.64	0.0001
R*L*HAND	9	477802.06272411	62.70	0.0001
SUBJNO*R*L(HAND)	108	5601394.97476196	61.26	0.0001
A	1	4091074.81272316	4831.96	0.0001
A*HAND	1	180010.35803509	212.61	0.0001
SUBJNO*A(HAND)	12	2940369.21361637	289.41	0.0001
R*A	3	1085026.15647316	427.17	0.0001
R*A*HAND	3	99831.38705349	39.30	0.0001
SUBJNO*R*A(HAND)	36	1511262.13459301	49.58	0.0001
L*A	3	1746589.67879391	687.63	0.0001
L*A*HAND	3	276672.57187653	108.93	0.0001
SUBJNO*L*A(HAND)	36	991233.38369846	32.52	0.0001
R*L*A	9	2268495.22700787	297.70	0.0001
R*L*A*HAND	9	658035.20089054	86.36	0.0001
SUBJNO*R*L*A(HAND)	108	3562740.95021534	38.96	0.0001
S	1	12090427.40089226	14279.97	0.0001
S*HAND	1	20022.28593731	23.65	0.0001
SUBJNO*S(HAND)	12	1396015.54754543	137.40	0.0001
R*S	3	179917.16383934	70.83	0.0001
R*S*HAND	3	20972.17968750	8.26	0.0001
SUBJNO*R*S(HAND)	36	1486433.27209377	48.77	0.0001
L*S	3	177660.63080406	69.94	0.0001
L*S*HAND	3	38696.72343826	15.23	0.0001
SUBJNO*L*S(HAND)	36	1456820.46762753	47.80	0.0001
R*L*S	9	519919.24017715	68.23	0.0001
R*L*S*HAND	9	436940.88950539	57.34	0.0001
SUBJNO*R*L*S(HAND)	108	3989529.77342987	43.63	0.0001
A*S	1	47566.87522316	56.20	0.0001
A*S*HAND	1	162217.35803604	191.59	0.0001
SUBJNO*A*S(HAND)	12	263338.02923775	25.92	0.0001
R*A*S	3	4268.16361523	1.68	0.1670
R*A*S*HAND	3	124058.03705311	48.84	0.0001
SUBJNO*R*A*S(HAND)	36	1030208.36183166	33.80	0.0001
L*A*S	3	57215.12343693	22.53	0.0001
L*A*S*HAND	3	36812.33437443	14.49	0.0001
SUBJNO*L*A*S(HAND)	36	1625075.08593464	53.32	0.0001
R*L*A*S	9	215536.53415203	28.29	0.0001
R*L*A*S*HAND	9	347348.33839417	45.58	0.0001
SUBJNO*R*L*A*S(HAND)	108	3705988.88368320	40.53	0.0001

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R	3	42716476.43437481	152.38	0.0001

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: PT

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*L(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
L	3	37258363.26562500	178.98	0.0001

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
A	1	4091074.81272316	16.70	0.0015

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
S	1	12090427.40089226	103.93	0.0001

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*L(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*L	9	5476046.84999943	11.73	0.0001

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*A	3	1085026.15647316	8.62	0.0002

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*S	3	179917.16383934	1.45	0.2438

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*L*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
L*S	3	177660.63080406	1.46	0.2408

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
A*S	1	47586.87522316	2.17	0.1666

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*L*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
L*A	3	1746589.67879391	21.14	0.0001

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: PT

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*L*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*L*A	9	2268495.22700787	7.64	0.0001

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*L*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*L*S	9	519919.24017715	1.56	0.1347

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*A*S	3	4268.16361523	0.05	0.9851

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*L*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
L*A*S	3	57215.12343693	0.42	0.7380

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*L*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*L*A*S	9	215536.53415203	0.70	0.7107

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*L*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*L*A*S*HAND	9	347348.33839417	1.12	0.3516

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*L*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
L*A*S*HAND	3	36812.33437443	0.27	0.8453

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*A*S*HAND	3	124058.03705311	1.45	0.2458

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*L*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*L*S*HAND	9	436940.88950539	1.31	0.2374

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: PT

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*L*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*L*A*HAND	9	658035.20089054	2.22	0.0262

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*L*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
L*A*HAND	3	276672.57187653	3.35	0.0295

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
A*S*HAND	1	162217.35803604	7.39	0.0186

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*L*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
L*S*HAND	3	38696.72343826	0.32	0.8117

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*S*HAND	3	20972.17968750	0.17	0.9164

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*A*HAND	3	99831.38705349	0.79	0.5060

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R*L(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*L*HAND	9	477802.06272411	1.02	0.4263

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
S*HAND	1	20022.28593731	0.17	0.6856

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
A*HAND	1	180010.35803509	0.73	0.4082

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: PT

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*L(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
L*HAND	3	669864.87522221	3.22	0.0341

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*R(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
R*HAND	3	78143.63504410	0.28	0.8404

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
HAND	1	747298.06272316	0.14	0.7140

APPENDIX C.2(a)

COMPUTATION OF COMPONENT VARIANCES OF SIGNIFICANT EFFECTS - ASYM-SIMO

From the results of ANOVA (Appendix C.2) and the EMS table (Table C2), we compute the component variances as follow:

Main Effects

$\sigma_e^2 = 846.67$

$\sigma_e^2 + 1280\,\sigma_O^2 = 5306555.6$ $\qquad \sigma_O^2 = 4145.75$

$\sigma_e^2 + 320\,\sigma_{RO}^2 = 93444.47$

$\sigma_e^2 + 4480\,\phi_R + 320\,\sigma_{RO}^2 = 14238825$ $\qquad \phi_R = 3157.45$

$\sigma_e^2 + 4480\,\phi_L + 320\,\sigma_{LO}^2 = 12419454$ $\qquad \phi_L = 2756.71$

$\sigma_e^2 + 320\,\sigma_{LO}^2 = 69391.205$

$\sigma_e^2 + 8960\,\phi_S + 640\,\sigma_{SO}^2 = 12090427.4$

$\sigma_e^2 + 640\,\sigma_{SO}^2 = 116334.62$ $\qquad \phi_S = 1336.39$

$\sigma_e^2 + 8960\,\phi_A + 640\,\sigma_{AO}^2 = 4091074.81$

$\sigma_e^2 + 640\,\sigma_{AO}^2 = 245030.76$ $\qquad \phi_A = 429.25$

Interaction Effects

$\sigma_e^2 + 1120\,\phi_{RL} + 80\,\sigma_{RLO}^2 = 608449.5$

$\sigma_e^2 + 80\,\sigma_{RLO}^2 = 51864.768$ $\qquad \phi_{RL} = 496.95$

$\sigma_e^2 + 2240\,\phi_{RA} + 160\,\sigma_{RAO}^2 = 361675.3$

$\sigma_e^2 + 160\ \sigma_{RAO}^2 = 41979.5$ $\qquad$ $\phi_{RA} = 142.72$

$\sigma_e^2 + 2240\ \phi_{LA} + 160\ \sigma_{LAO}^2 = 582196.5$

$\sigma_e^2 + 160\ \sigma_{LAO}^2 = 27534.25$ $\qquad$ $\phi_{LA} = 247.62$

$\sigma_e^2 + 560\ \phi_{RLA} + 40\ \sigma_{RLAO}^2 = 252055.0$

$\sigma_e^2 + 40\ \sigma_{RLAO}^2 = 32988.33$ $\qquad$ $\phi_{RLA} = 391.19$

$\sigma_e^2 + 280\ \phi_{RLAH} + 40\ \sigma_{RLAO}^2 = 73115.$

$\sigma_e^2 + 40\ \sigma_{RLAO}^2 = 32988.33$ $\qquad$ $\phi_{RLAH} = 143.31$

$\sigma_e^2 + 1120\ \phi_{LAH} + 160\ \sigma_{LAO}^2 = 92224.$

$\sigma_e^2 + 160\ \sigma_{LAO}^2 = 27534.25$ $\qquad$ $\phi_{LAH} = 57.76$

$\sigma_e^2 + 2240\ \phi_{SAH} + 320\ \sigma_{SAO}^2 = 162217.36$

$\sigma_e^2 + 320\ \sigma_{SAO}^2 = 21944.8$ $\qquad$ $\phi_{SAH} = 62.62$

$\sigma_e^2 + 2240\ \phi_{LH} + 320\ \sigma_{LO}^2 = 223288.29$

$\sigma_e^2 + 320\ \sigma_{LO}^2 = 69391.2$ $\qquad$ $\phi_{LH} = 68.7$

Total variances = 13436.42

Therefore

% variance: Subject	= 30.85 %	R*L*A*H	= 1.07 %
R	= 23.50 %	L*A*H	= 0.43 %
L	= 20.52 %	S*A*H	= 0.47 %
S	= 9.95 %	L*H	= 0.51 %
A	= 3.19 %		
Sub-total	= 88.01 %		2.48 %

R*L = 3.70 %

R*A = 1.06 %

L*A = 1.84 %

R*L*A = 2.91 %

Sub-total = 9.51 %

APPENDIX C.3

NORMALITY TEST - STUDY #2

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   22:25 FRIDAY, JUNE 9, 1978   51

SUBJNO=1   CONDNJ=51

VARIABLE	N	D-MAX	PROB	SKEWNESS G1	G1/SERG1	P-LEVEL G1	KURTOSIS G2	G2/SERG2	P-LEVEL G2	MEAN	ST DEV
PT	39	0.1607	.05	-0.521	-1.378	0.168	-0.617	-0.832	0.405	493.2308	15.5537
PR	39	0.1622	.05	-0.548	-1.448	0.148	-0.568	-0.766	0.443	493.1538	15.7037
PL	39	0.0997	>.20	-0.377	-0.997	0.319	-0.662	-0.894	0.371	456.3077	22.7621

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   22:25 FRIDAY, JUNE 9, 1978   115

SUBJNO=2   CONDNJ=51

VARIABLE	N	D-MAX	PROB	SKEWNESS G1	G1/SERG1	P-LEVEL G1	KURTOSIS G2	G2/SERG2	P-LEVEL G2	MEAN	ST DEV
PT	30	0.1339	.20	0.234	0.548	0.583	-0.605	-0.726	-0.468	550.5000	18.2185
PR	30	0.1339	.20	0.234	0.548	0.583	-0.605	-0.726	0.463	550.5000	18.2185
PL	30	0.1209	>.20	-0.595	-1.394	0.163	0.938	1.126	0.260	477.7000	37.5170

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   22:25 FRIDAY, JUNE 9, 1978   179

SUBJNO=3   CONDNJ=51

VARIABLE	N	D-MAX	PROB	SKEWNESS G1	G1/SERG1	P-LEVEL G1	KURTOSIS G2	G2/SERG2	P-LEVEL G2	MEAN	ST DEV
PT	49	0.1729	.01	-1.249	-3.676	0.000	1.780	2.665	0.008	418.6531	27.0975
PR	49	0.1729	.01	-1.249	-3.676	0.000	1.780	2.665	0.008	418.6531	27.0975
PL	49	0.0933	>.20	-0.892	-2.625	0.009	0.679	1.016	0.310	337.4694	27.8284

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   22:25 FRIDAY, JUNE 9, 1978   243

SUBJNO=4   CONDNJ=51

VARIABLE	N	D-MAX	PROB	SKEWNESS G1	G1/SERG1	P-LEVEL G1	KURTOSIS G2	G2/SERG2	P-LEVEL G2	MEAN	ST DEV
PT	41	0.2221	.01	-1.463	-3.958	0.000	3.027	4.178	0.000	594.5854	28.5254
PR	41	0.2042	.01	-1.196	-3.236	0.001	1.702	2.350	0.019	590.7805	30.0479
PL	41	0.1253	.15	-0.656	-1.775	0.076	0.022	0.030	0.976	568.7561	35.6292

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STATISTICAL ANALYSIS SYSTEM 22:25 FRIDAY, JUNE 9, 1978 307

SUBJNO=5 CONDNJ=51

VARIABLE	N	D-MAX	PROB	SKEWNESS G1	G1/SERG1	P-LEVEL G1	KURTOSIS G2	G2/SERG2	P-LEVEL G2	MEAN	ST DEV
PT	42	0.1313	.10	-0.146	-0.399	0.690	0.682	0.951	0.341	515.2143	24.4715
PR	42	0.1236	.10	-0.149	-0.407	0.684	0.715	0.998	0.318	510.7857	23.1628
PL	42	0.1082	>.20	0.471	1.290	0.197	0.298	0.415	0.678	479.7143	34.4980

STATISTICAL ANALYSIS SYSTEM 22:25 FRIDAY, JUNE 9, 1978 371

SUBJNO=6 CONDNJ=51

VARIABLE	N	D-MAX	PROB	SKEWNESS G1	G1/SERG1	P-LEVEL G1	KURTOSIS G2	G2/SERG2	P-LEVEL G2	MEAN	ST DEV
PT	31	0.1584	.10	-0.399	-0.948	0.343	-1.254	-1.528	0.127	560.4194	31.3536
PR	31	0.1631	.05	-0.255	-0.607	0.544	-1.317	-1.605	0.108	556.8387	33.1603
PL	31	0.1326	.20	-0.472	-1.123	0.261	-0.697	-0.849	0.396	516.8710	42.7939

STATISTICAL ANALYSIS SYSTEM 22:25 FRIDAY, JUNE 9, 1978 434

SUBJNO=7 CONDNJ=50

VARIABLE	N	D-MAX	PROB	SKEWNESS G1	G1/SERG1	P-LEVEL G1	KURTOSIS G2	G2/SERG2	P-LEVEL G2	MEAN	ST DEV
PT	43	0.0873	>.20	-0.053	-0.147	0.883	-0.802	-1.132	0.258	472.9535	14.0542
PR	43	0.0825	>.20	0.067	0.185	0.853	-0.819	-1.155	0.248	472.0465	14.2210
PL	43	0.1188	.15	-0.071	-0.197	0.844	-0.887	-1.251	0.211	450.4884	19.4855

STATISTICAL ANALYSIS SYSTEM 22:25 FRIDAY, JUNE 9, 1978 499

SUBJNO=11 CONDNJ=51

VARIABLE	N	D-MAX	PROB	SKEWNESS G1	G1/SERG1	P-LEVEL G1	KURTOSIS G2	G2/SERG2	P-LEVEL G2	MEAN	ST DEV
PT	34	0.1266	.20	-0.484	-1.201	0.230	0.581	0.737	0.461	685.4118	30.8271
PR	34	0.1273	.20	-0.654	-1.623	0.105	0.440	0.559	0.576	677.2059	39.1383
PL	34	0.0899	>.20	-0.578	-1.435	0.151	0.953	1.209	0.226	658.4118	29.5902

STATISTICAL ANALYSIS SYSTEM 22:25 FRIDAY, JUNE 9, 1978 563

SUBJNO=12 CONDNJ=51

VARIABLE	N	D-MAX	PROB	SKEWNESS G1	G1/SERG1	P-LEVEL G1	KURTOSIS G2	G2/SERG2	P-LEVEL G2	MEAN	ST DEV
PT	36	0.1178	>.20	-0.433	-1.104	0.270	-0.363	-0.472	0.637	646.8333	35.2513
PR	36	0.1298	.15	-0.361	-0.919	0.358	-0.406	-0.529	0.597	645.6667	35.3157
PL	36	0.1637	.05	-0.765	-1.950	0.051	-0.664	-0.855	0.387	618.6667	47.5863

STATISTICAL ANALYSIS SYSTEM 22:25 FRIDAY, JUNE 9, 1978 627

SUBJNO=13 CONDNJ=51

VARIABLE	N	D-MAX	PROB	SKEWNESS G1	G1/SERG1	P-LEVEL G1	KURTOSIS G2	G2/SERG2	P-LEVEL G2	MEAN	ST DEV
PT	41	0.0830	>.20	0.278	0.754	0.451	0.192	0.265	0.791	458.4878	17.7216
PR	41	0.0757	>.20	0.291	0.788	0.431	0.158	0.218	0.827	458.2683	17.8340
PL	41	0.1179	.20	-0.325	-0.879	0.380	-0.195	-0.270	0.787	425.7073	19.9990

STATISTICAL ANALYSIS SYSTEM 22:25 FRIDAY, JUNE 9, 1978 691

SUBJNO=14 CONDNJ=51

VARIABLE	N	D-MAX	PROB	SKEWNESS G1	G1/SERG1	P-LEVEL G1	KURTOSIS G2	G2/SERG2	P-LEVEL G2	MEAN	ST DEV
PT	32	0.1759	.05	1.887	4.553	0.000	5.477	6.767	0.000	491.5313	61.4681
PR	32	0.1754	.05	1.850	4.464	0.000	5.390	6.659	0.000	491.3438	61.7490
PL	32	0.1224	>.20	-0.117	-0.282	0.778	-1.405	-1.736	0.083	410.8125	39.3884

STATISTICAL ANALYSIS SYSTEM 22:25 FRIDAY, JUNE 9, 1978 755

SUBJNO=15 CONDNO=51

VARIABLE	N	D-MAX	PROB	SKEWNESS G1	G1/SERG1	P-LEVEL G1	KURTOSIS G2	G2/SERG2	P-LEVEL G2	MEAN	ST DEV
PT	38	0.1036	>.20	0.098	0.255	0.799	-1.009	-1.346	0.178	575.8421	38.5196
PR	38	0.0995	>.20	0.065	0.171	0.865	-1.037	-1.383	0.167	573.4737	37.6159
PL	38	0.0759	>.20	-0.201	-0.524	0.600	-0.506	-0.676	0.499	547.6579	55.5222

STATISTICAL ANALYSIS SYSTEM 22:25 FRIDAY, JUNE 9, 1978 819

SUBJNO=16 CONDNJ=51

VARIABLE	N	D-MAX	PROB	SKEWNESS G1	G1/SERG1	P-LEVEL G1	KURTOSIS G2	G2/SERG2	P-LEVEL G2	MEAN	ST DEV
PT	39	0.1154	>.20	0.485	1.282	0.200	-0.461	-0.623	0.534	390.0000	17.0957
PR	39	0.1136	>.20	0.485	1.281	0.200	-0.481	-0.650	0.516	389.9231	17.1578
PL	39	0.1655	.01	-0.004	-0.012	0.991	-1.343	-1.812	0.070	367.3077	22.2677

STATISTICAL ANALYSIS SYSTEM 22:25 FRIDAY, JUNE 9, 1978 883

SUBJNO=17 CONDNJ=51

VARIABLE	N	D-MAX	PROB	SKEWNESS G1	G1/SERG1	P-LEVEL G1	KURTOSIS G2	G2/SERG2	P-LEVEL G2	MEAN	ST DEV
PT	42	0.0907	>.20	0.268	0.733	0.464	-0.454	-0.633	0.527	545.5000	23.2466
PR	42	0.0907	>.20	0.268	0.733	0.464	-0.454	-0.633	0.527	545.5000	23.2466
PL	42	0.1160	.20	0.280	0.766	0.444	-0.418	-0.584	0.559	433.2143	26.5041

APPENDIX C.4

MULTIPLE REGRESSION ANALYSIS WITH HANDEDNESS INTERACTION TERMS

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	12	105221656.55719231	8768471.37976603	1301.94	0.0001	0.465945	15.5052
ERROR	17907	120602550.53566523	6734.93888343		STD DEV		PT MEAN
CORRECTED TOTAL	17919	225824207.14285755			82.06667340		529.28571429

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
R	1	42688370.99218782	6338.35	0.0001	1	436316.82966980	64.78	0.0001
L	1	37195943.00245744	5522.83	0.0001	1	301804.93562155	44.81	0.0001
A	1	4091074.41272320	607.44	0.0001	1	445335.45352137	66.12	0.0001
S	1	12090427.40037238	1795.18	0.0001	1	3180610.43696424	472.26	0.0001
R*L	1	4057925.54150328	602.52	0.0001	1	317956.92500077	47.21	0.0001
R*A	1	733945.01795719	108.98	0.0001	1	649334.31857128	96.41	0.0001
L*A	1	1249083.72504471	185.46	0.0001	1	705462.11085054	104.70	0.0001
R*L*A	1	1602383.04014263	237.92	0.0001	1	1386482.35555882	205.86	0.0001
R*L*A*HAND	1	1226288.71750001	182.08	0.0001	1	65.62500000	0.01	0.9214
L*A*HAND	1	236545.94350001	35.12	0.0001	1	216179.48625166	32.10	0.0001
A*S*HAND	1	16322.99612002	2.42	0.1195	1	16322.99612002	2.42	0.1195
L*HAND	1	33309.36685714	4.95	0.0262	1	33309.36685714	4.95	0.0262

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	257.75329110	21.28	0.0001	12.11360706
R	34.18633929	8.05	0.0001	4.24735387
L	31.73848214	6.69	0.0001	4.74803598
A	-61.76877970	-8.13	0.0001	7.59515153
S	49.03334165	21.73	0.0001	2.25495191
R*L	10.65620786	6.87	0.0001	1.55091435
R*A	26.37642857	9.82	0.0001	2.68620245
L*A	32.87126767	10.23	0.0001	3.21246785
R*L*A	-15.09035714	-14.35	0.0001	1.05138129
R*L*A*HAND	-0.02500000	-0.10	0.9214	0.25326325
L*A*HAND	-6.65435662	-5.67	0.0001	1.17453418
A*S*HAND	1.30942752	1.56	0.1195	0.84110140
L*HAND	3.14857143	2.22	0.0262	1.41578462

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL FOR MEAN	UPPER 95% CL FOR MEAN
1	285.00000000	363.56272308	-78.56272308	358.59764350	368.52780266
2	288.00000000	363.56272308	-75.56272308	358.59764350	368.52780266
3	300.00000000	363.56272308	-63.56272308	358.59764350	368.52780266
4	297.00000000	363.56272308	-66.56272308	358.59764350	368.52780266
5	258.00000000	363.56272308	-105.56272308	358.59764350	368.52780266
6	291.00000000	363.56272308	-72.56272308	358.59764350	368.52780266
7	300.00000000	363.56272308	-63.56272308	358.59764350	368.52780266
8	288.00000000	363.56272308	-75.56272308	358.59764350	368.52780266
9	276.00000000	363.56272308	-87.56272308	358.59764350	368.52780266
10	303.00000000	363.56272308	-60.56272308	358.59764350	368.52780266
11	297.00000000	363.56272308	-66.56272308	358.59764350	368.52780266
12	306.00000000	363.56272308	-57.56272308	358.59764350	368.52780266
13	252.00000000	363.56272308	-111.56272308	358.59764350	368.52780266
14	300.00000000	363.56272308	-63.56272308	358.59764350	368.52780266
15	297.00000000	363.56272308	-66.56272308	358.59764350	368.52780266
16	276.00000000	363.56272308	-87.56272308	358.59764350	368.52780266
17	258.00000000	363.56272308	-105.56272308	358.59764350	368.52780266
18	249.00000000	363.56272308	-114.56272308	358.59764350	368.52780266
19	243.00000000	363.56272308	-120.56272308	358.59764350	368.52780266
20	252.00000000	363.56272308	-111.56272308	358.59764350	368.52780266
21	480.00000000	361.34136541	118.65863459	356.27467945	366.40805138
22	477.00000000	361.34136541	115.65863459	356.27467945	366.40805138
23	498.00000000	361.34136541	136.65863459	356.27467945	366.40805138
24	483.00000000	361.34136541	121.65863459	356.27467945	366.40805138
25	441.00000000	361.34136541	79.65863459	356.27467945	366.40805138
26	465.00000000	361.34136541	103.65863459	356.27467945	366.40805138

APPENDIX C.5

MULTIPLE REGRESSION ANALYSIS WITHOUT HANDEDNESS INTERACTION TERMS

STATISTICAL ANALYSIS SYSTEM 17:07 SUNDAY, JUNE 11, 1978 1

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	8	103709188.53321514	12963648.56665189	1901.42	0.0001	0.459247	15.6004
ERROR	17911	122115018.60954240	6817.87832112		STD DEV		PT MEAN
CORRECTED TOTAL	17919	225824207.14285755			82.57044460		529.28571429

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
R	1	42688390.91218782	6261.24	0.0001	1	436316.82966980	64.00	0.0001
L	1	37175943.30245744	5452.65	0.0001	1	497702.41466381	73.00	0.0001
A	1	4091074.81272320	600.05	0.0001	1	430592.46450880	63.16	0.0001
S	1	12090427.40089288	1773.34	0.0001	1	12090427.40089288	1773.34	0.0001
R*L	1	4057925.54150928	595.19	0.0001	1	317956.92500077	46.64	0.0001
R*A	1	733945.01785719	107.65	0.0001	1	649334.91357128	95.24	0.0001
L*A	1	1249084.72504471	183.21	0.0001	1	489010.51506683	71.72	0.0001
R*L*A	1	1602388.04014263	235.03	0.0001	1	1602388.04014263	235.03	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	253.34397321	21.38	0.0001	11.84854816
R	34.10633929	8.00	0.0001	4.27342650
L	36.51133929	8.54	0.0001	4.27342650
A	-58.02276786	-7.85	0.0001	7.40179163
S	51.94955357	42.11	0.0001	1.23363197
R*L	10.65826786	6.83	0.0001	1.56043473
R*A	26.37642857	9.76	0.0001	2.70275223
L*A	22.88973214	8.47	0.0001	2.70275223
R*L*A	-15.12135714	-15.33	0.0001	0.98690558

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL FOR MEAN	UPPER 95% CL FOR MEAN
1	285.00000000	361.96100893	-76.96100893	357.02314833	366.89886953
2	288.00000000	361.96100893	-73.96100893	357.02314833	366.89886953
3	300.00000000	361.96100893	-61.96100893	357.02314833	366.89886953
4	297.00000000	361.96100893	-64.96100893	357.02314833	366.89886953
5	258.00000000	361.96100893	-103.96100893	357.02314833	366.89886953
6	291.00000000	361.96100893	-70.96100893	357.02314833	366.89886953
7	300.00000000	361.96100893	-61.96100893	357.02314833	366.89886953
8	288.00000000	361.96100893	-73.96100893	357.02314833	366.89886953
9	276.00000000	361.96100893	-85.96100893	357.02314833	366.89886953
10	303.00000000	361.96100893	-58.96100893	357.02314833	366.89886953
11	297.00000000	361.96100893	-64.96100893	357.02314833	366.89886953
12	306.00000000	361.96100893	-55.96100893	357.02314833	366.89886953
13	252.00000000	361.96100893	-109.96100893	357.02314833	366.89886953
14	300.00000000	361.96100893	-61.96100893	357.02314833	366.89886953
15	297.00000000	361.96100893	-64.96100893	357.02314833	366.89886953
16	276.00000000	361.96100893	-85.96100893	357.02314833	366.89886953
17	258.00000000	361.96100893	-103.96100893	357.02314833	366.89886953
18	249.00000000	361.96100893	-112.96100893	357.02314833	366.89886953
19	243.00000000	361.96100893	-118.96100893	357.02314833	366.89886953
20	252.00000000	361.96100893	-109.96100893	357.02314833	366.89886953
21	480.00000000	361.96100893	118.03899107	357.02314833	366.89886953
22	477.00000000	361.96100893	115.03899107	357.02314833	366.89886953
23	498.00000000	361.96100893	136.03899107	357.02314833	366.89886953
24	483.00000000	361.96100893	121.03899107	357.02314833	366.89886953
25	441.00000000	361.96100893	79.03899107	357.02314833	366.89886953
26	465.00000000	361.96100893	103.03899107	357.02314833	366.89886953
27	459.00000000	361.96100893	97.03899107	357.02314833	366.89886953
28	477.00000000	361.96100893	115.03899107	357.02314833	366.89886953
29	462.00000000	361.96100893	100.03899107	357.02314833	366.89886953
30	456.00000000	361.96100893	94.03899107	357.02314833	366.89886953
31	456.00000000	361.96100893	94.03899107	357.02314833	366.89886953
32	462.00000000	361.96100893	100.03899107	357.02314833	366.89886953
33	474.00000000	361.96100893	112.03899107	357.02314833	366.89886953
34	426.00000000	361.96100893	64.03899107	357.02314833	366.89886953

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APPENDIX C.6

DUNCAN'S MEANS TESTS - GENERAL SIMO

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=17856   MS=6602.24

GROUPING				MEAN	N	CONDNO
		A		711.578571	280	48
		B		673.457143	280	44
C		B		664.821429	280	47
C				652.371429	280	16
		D		629.003571	280	43
E		D		620.496429	280	46
E		D		618.750000	280	64
E		F		606.385714	280	12
		F		603.235714	280	15
		F		602.832143	280	40
		F		602.775000	280	60
G		F		599.817857	280	39
G		F	H	591.278571	280	56
G		I	H	586.671429	280	62
J		I	H	582.985714	280	42
J		I	H	581.871429	280	63
J	K	I	H	578.614286	280	52
J	K	I	H	577.317857	280	59
J	K	I	H	576.803571	280	45
J	K	I	L	571.350000	280	8
J	K		L	570.063571	280	61
J	K		L	567.432143	280	36
	K	M	L	566.014286	280	11
	K	M	L	565.767857	280	24
N		M	L	559.296429	280	32
N		M	O	552.032143	280	58
N		M	O	551.185714	280	20
N		P	O	547.275000	280	28
N		P	O	545.625000	280	14
Q		P	O	542.453571	280	31
Q		P	O	540.503571	280	30
Q		P	R	535.650000	280	38

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S T A T I S T I C A L   A N A L Y S I S   S Y S T E M        19:00 SATURDAY, JUNE 3, 1978    7
                    GENERAL LINEAR MODELS PROCEDURE
               DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

          MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.
               ALPHA LEVEL=.05         DF=17856     MS=6602.24

                GROUPING                    MEAN        N     CONDNO
                Q       P    R
                Q    S  P    R          533.957143    280     10
                Q    S  P    R
                Q    S  P    R          532.467857    280      4
                Q    S       R
                Q    S  T    R          529.414286    280     51
                Q    S  T    R
                Q    S  T    R          528.867857    280     55
                     S  T    R
                U    S  T    R          520.971429    280     35
                U    S  T    R
                U    S  T    R          520.510714    280     29
                U    S  T
                U    S  T               518.823571    280     13
                U       T
                U       T               516.246429    280     57
                U       T
                U       T               514.050714    280     41
                U
                U       V               509.978571    280      7
                        V
                W       V               498.107143    280     37
                W
                W                       494.539286    280     25
                W
                W                       492.707143    280     19
                W
                W                       491.560714    280     26
                W
                W       X               487.521429    280      3
                W       X
                W       X               484.173571    280     27
                        X
                Y       X               475.317857    280      6
                Y       X
                Y       X    Z          474.525000    280     34
                Y       X    Z
                Y       X    Z          473.892857    280     54
                Y            Z
                Y            Z          466.875000    280     50
                Y            Z
                Y            Z          466.789286    280     23
                Y            Z
                Y            Z          465.535714    280      9
                             Z
                             Z          459.471429    280     53

                        A               442.467857    280      5

                        B               420.910714    280      2
                        B
                        B               420.546429    280     18
                        B
                        B               419.925000    280     21
                        B
                        B               413.571429    280     22

                        C               382.210714    280     49
                        C
                        C               379.350000    280     33

                        D               336.685714    280      1
                        D
                        D               326.485714    280     17
```

APPENDIX C.7

DUNCAN'S MEANS TESTS OF MAIN EFFECTS

(R, L, A, S)

STATISTICAL ANALYSIS SYSTEM 12:30 SUNDAY, JULY 9, 1978 17

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05 DF=17852 MS=6479.62

GROUPING	MEAN	N	R
A	595.807366	4480	4
B	549.060268	4480	3
C	508.445089	4480	2
D	463.830134	4480	1

STATISTICAL ANALYSIS SYSTEM 12:30 SUNDAY, JULY 9, 1978 18

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05 DF=17852 MS=6479.62

GROUPING	MEAN	N	L
A	583.366964	4480	4
B	552.332812	4480	3
C	509.695982	4480	2
D	466.747098	4480	1

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=17852   MS=6479.62

GROUPING	MEAN	N	A
A	544.395201	8960	1
B	514.176228	8960	2

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=17852   MS=6479.62

GROUPING	MEAN	N	S
A	555.260491	8960	2
B	503.310937	8960	1

APPENDIX C.8

ANOVA - SYM-SIMO OF STUDY #2

MULTIPLE REGRESSION FOR SIMO   18:47 MONDAY, JULY 3, 1978   104

ANALYSIS OF VARIANCE PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
SUBJNO	7	1 2 3 4 5 6 7
B	4	1 2 3 4
A	2	1 2
S	2	1 2
HAND	2	1 2

NUMBER OF OBSERVATIONS IN DATA SET = 4480

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: SYMPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R SQUARE	C.V.
MODEL	223	82572303.95155847	370279.38991730	436.06	0.0001	0.958067	5.7407
ERROR	4256	3614008.95000416	849.15623825		STD DEV		SYMPT MEAN
CORRECTED TOTAL	4479	86186312.90156263			29.14028549		507.60468750

SOURCE	DF	ANOVA SS	F VALUE	PR > F
HAND	1	604662.99308038	712.08	0.0001
SUBJNO(HAND)	12	15116492.61160707	1463.48	0.0001
B	3	48797535.01138383	19155.30	0.0001
B*HAND	3	322472.64174110	126.59	0.0001
SUBJNO*B(HAND)	36	1724951.30624902	56.43	0.0001
A	1	3547970.00558037	4178.23	0.0001
A*HAND	1	125282.02700883	147.54	0.0001
SUBJNO*A(HAND)	12	843812.55803555	62.81	0.0001
B*A	3	1190687.48638391	467.40	0.0001
B*A*HAND	3	218343.78281236	85.71	0.0001
SUBJNO*B*A(HAND)	36	777926.85267806	25.45	0.0001
S	1	4267728.24308038	5025.85	0.0001
S*HAND	1	11697.12522316	13.77	0.0002
SUBJNO*S(HAND)	12	895485.89732099	67.88	0.0001
B*S	3	120867.93102683	47.45	0.0001
B*S*HAND	3	157527.48816937	61.84	0.0001
SUBJNO*B*S(HAND)	36	1409865.67767859	46.12	0.0001
A*S	1	33032.86272317	38.90	0.0001
A*S*HAND	1	179744.22522312	211.67	0.0001
SUBJNO*A*S(HAND)	12	690783.11517347	67.79	0.0001
B*A*S	3	42543.72924089	16.70	0.0001
B*A*S*HAND	3	221589.13459849	86.98	0.0001
SUBJNO*B*A*S(HAND)	36	1271301.19553453	41.59	0.0001

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
HAND	1	604662.99308038	0.48	0.5016

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
A	1	3547970.00558037	50.46	0.0001

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*B(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
B	3	48797535.01138383	339.47	0.0001

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
S	1	4267728.24308038	57.19	0.0001

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: SYMPT

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
A*S	1	33032.86272317	0.57	0.4634

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*B*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
B*S	3	120867.98102683	1.03	0.3914

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*B*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
B*A	3	1190687.48638391	18.37	0.0001

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*B*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
B*A*S	3	42543.72924089	0.40	0.7527

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
A*HAND	1	125282.02700883	1.78	0.2067

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*B(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
B*HAND	3	322472.64174110	2.24	0.0999

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
S*HAND	1	11697.12522316	0.16	0.6991

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
A*S*HAND	1	179744.22522312	3.12	0.1026

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*B*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
B*A*HAND	3	218343.78281236	3.37	0.0290

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: SYMPT

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*B*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
B*S*HAND	3	157527.48816937	1.34	0.2704

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*B*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
B*A*S*HAND	3	221589.13459849	2.09	0.1185

APPENDIX C.9
COMPUTATION OF COMPONENT VARIANCES OF SIGNIFICANT EFFECTS - SYM-SIMO

From the results of ANOVA (Appendix C.8) and the EMS table (Table C4), we compute the component variances as follow:

Main Effects

$\sigma_e^2 = 849.156$

$\sigma_e^2 + 320\ \sigma_O^2 = 1259707.6$ $\qquad \sigma_O^2 = 3933.932$

$\sigma_e^2 + 80\ \sigma_{BO}^2 = 47915.31$

$\sigma_e^2 + 1120\ \phi_B + 80\ \sigma_{BO}^2 = 16265845.0$ $\qquad \phi_B = 14480.294$

$\sigma_e^2 + 160\ \sigma_{AO}^2 = 70317.713$

$\sigma_e^2 + 2240\ \phi_A + 160\ \sigma_{AO}^2\ 3547970.0$ $\qquad \phi_A = 1552.523$

$\sigma_e^2 + 160\ \sigma_{SO}^2 = 74623.83$

$\sigma_e^2 + 2240\ \phi_S + 160\ \sigma_{SO}^2 = 4267728.2$ $\qquad \phi_S = 1871.922$

Interaction Effects

$\sigma_e^2 + 40\ \sigma_{BAO}^2 = 21609.079$

$\sigma_e^2 + 560\ \phi_{BA} + 40\ \sigma_{BAO}^2 = 396895.6$ $\qquad \phi_{BA} = 670.155$

$\sigma_e^2 + 40\ \sigma_{BAO}^2 = 21609.079$

$\sigma_e^2 + 280\ \phi_{BAH} + 40\ \sigma_{BAO}^2 = 72781.26$ $\qquad \phi_{BAH} = 182.758$

Total variance = 22691.584

Therefore

% variance:	Subject	= 17.34 %
	B	= 63.81 %
	A	= 6.84 %
	S	= 8.25 %
	B*A	= 2.95 %
	B*A*H	= 0.81 %

APPENDIX C.10

MULTIPLE REGRESSION ANALYSIS - SYM-SIMO

STATISTICAL ANALYSIS SYSTEM 23:06 THURSDAY, AUGUST 3, 1978

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SYMPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	5	57955601.91021447	11591120.38384289	1836.96	0.0001	0.672446	15.64
ERROR	4474	28230710.98234816	6309.94881143		STD DEV		SYMPT MEAN
CORRECTED TOTAL	4479	86186312.90155263			79.43518623		507.604687

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
B	1	48171103.80468762	7634.15	0.0001	1	10006665.88501808	1585.86	0.0001
A	1	3547970.03558030	562.28	0.0001	1	26568.90535715	4.21	0.04
S	1	4267728.24308041	676.35	0.0001	1	4267728.24308041	676.35	0.0001
B*A	1	1042300.64290186	165.18	0.0001	1	365289.34857768	57.89	0.0001
B*A*HAND	1	926499.22296429	146.83	0.0001	1	926499.22296429	146.83	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	165.24843750	16.76	0.0001	9.85821888
B	133.67517857	39.82	0.0001	3.35674928
A	11.93035714	2.05	0.0402	5.81406030
S	61.72901786	26.01	0.0001	2.37358018
B*A	-17.32221429	-7.61	0.0001	2.27665813
B*A*HAND	-6.64221429	-12.12	0.0001	0.54815486

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL FOR MEAN	UPPER 95% CL FOR MEAN
4457	477.00000000	529.95286607	-52.95286607	524.58621995	535.31951219
4458	495.00000000	529.95286607	-34.95286607	524.58621995	535.31951219
4459	492.00000000	529.95286607	-37.95286607	524.58621995	535.31951219
4460	477.00000000	529.95286607	-52.95286607	524.58621995	535.31951219
4461	624.00000000	602.41475893	21.58524107	595.05206954	609.77744832
4462	582.00000000	602.41475893	-20.41475893	595.05206954	609.77744832
4463	573.00000000	602.41475893	-29.41475893	595.05206954	609.77744832
4464	570.00000000	602.41475893	-32.41475893	595.05206954	609.77744832
4465	603.00000000	602.41475893	0.58524107	595.05206954	609.77744832
4466	627.00000000	602.41475893	24.58524107	595.05206954	609.77744832
4467	648.00000000	602.41475893	45.58524107	595.05206954	609.77744832
4468	636.00000000	602.41475893	33.58524107	595.05206954	609.77744832
4469	564.00000000	602.41475893	-38.41475893	595.05206954	609.77744832
4470	636.00000000	602.41475893	33.58524107	595.05206954	609.77744832
4471	588.00000000	602.41475893	-14.41475893	595.05206954	609.77744832
4472	597.00000000	602.41475893	-5.41475893	595.05206954	609.77744832
4473	618.00000000	602.41475893	15.58524107	595.05206954	609.77744832
4474	618.00000000	602.41475893	15.58524107	595.05206954	609.77744832
4475	561.00000000	602.41475893	-41.41475893	595.05206954	609.77744832
4476	585.00000000	602.41475893	-17.41475893	595.05206954	609.77744832
4477	576.00000000	602.41475893	-26.41475893	595.05206954	609.77744832
4478	609.00000000	602.41475893	6.58524107	595.05206954	609.77744832
4479	606.00000000	602.41475893	3.58524107	595.05206954	609.77744832
4480	618.00000000	602.41475893	15.58524107	595.05206954	609.77744832

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	28230710.98234421
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000394
FIRST ORDER AUTOCORRELATION	0.87415280
DURBIN-WATSON D	0.25167528

STATISTICAL ANALYSIS SYSTEM 23:06 THURSDAY, AUGUST 3, 1978

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SYMPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	55986802.05833834	18662267.35111611	2766.02	0.0001	0.649602	16.1819
ERROR	4476	30199510.84321429	6746.98633785		STD DEV		SYMPT MEAN
CORRECTED TOTAL	4479	86186312.90155263			82.14004101		507.60468

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
3	1	48171103.80468762	7139.65	0.0001	1	48171103.80468762	7139.65	0.0001
4	1	3547970.00558030	525.86	0.0001	1	3547970.00558030	525.86	0.0001
5	1	4267728.24308041	632.54	0.0001	1	4267728.24308041	632.54	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	267.56919643	44.51	0.0001	6.01203540
3	92.74687500	84.50	0.0001	1.09764247
4	-56.28340214	-22.93	0.0001	2.45440317
5	61.72901786	25.15	0.0001	2.45440317

STATISTICAL ANALYSIS SYSTEM 23:06 THURSDAY, AUGUST 3, 1978

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SYMPT

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL FOR MEAN	UPPER 95% CL FOR MEAN
4461	624.00000000	649.44776786	-25.44776786	644.17656529	654.71897042
4462	582.00000000	649.44776786	-67.44776786	644.17656529	654.71897042
4463	573.00000000	649.44776786	-76.44776786	644.17656529	654.71897042
4464	570.00000000	649.44776786	-79.44776786	644.17656529	654.71897042
4465	603.00000000	649.44776786	-46.44776786	644.17656529	654.71897042
4466	627.00000000	649.44776786	-22.44776786	644.17656529	654.71897042
4467	648.00000000	649.44776786	-1.44776786	644.17656529	654.71897042
4468	636.00000000	649.44776786	-13.44776786	644.17656529	654.71897042
4469	564.00000000	649.44776786	-85.44776786	644.17656529	654.71897042
4470	636.00000000	649.44776786	-13.44776786	644.17656529	654.71897042
4471	588.00000000	649.44776786	-61.44776786	644.17656529	654.71897042
4472	597.00000000	649.44776786	-52.44776786	644.17656529	654.71897042
4473	618.00000000	649.44776786	-31.44776786	644.17656529	654.71897042
4474	618.00000000	649.44776786	-31.44776786	644.17656529	654.71897042
4475	561.00000000	649.44776786	-88.44776786	644.17656529	654.71897042
4476	585.00000000	649.44776786	-64.44776786	644.17656529	654.71897042
4477	576.00000000	649.44776786	-73.44776786	644.17656529	654.71897042
4478	609.00000000	649.44776786	-40.44776786	644.17656529	654.71897042
4479	606.00000000	649.44776786	-43.44776786	644.17656529	654.71897042
4480	618.00000000	649.44776786	-31.44776786	644.17656529	654.71897042

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	30199510.84821018
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000411
FIRST ORDER AUTOCORRELATION	0.88193796
DURBIN-WATSON D	0.23609473

APPENDIX C.11

DUNCAN'S MEANS TESTS OF MAIN EFFECTS (B, A, S) OF SYM-SIMO

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   23:06 THURSDAY, AUGUST 3, 1978

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE SYMPT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=4474   MS=6609.99

GROUPING	MEAN	N	B
A	67[illegible].499107	1120	4
B	5[illegible].123571	1120	3
C	474.608036	1120	2
D	35[illegible].183036	1120	1

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   23:06 THURSDAY, AUGUST 3, 1978

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE SYMPT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=4474   MS=6609.99

GROUPING	MEAN	N	A
A	535.746429	2240	1
B	479.462946	2240	2

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   23:06 THURSDAY, AUGUST 3, 1978

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE SYMPT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=4474   MS=6609.99

GROUPING	MEAN	N	S
A	538.469196	2240	2
B	47[illegible].740179	2240	1

APPENDIX D.0

STUDY #3 - SINGLE-HANDED REACH MOTIONS

Condition Number	Symbol
1	$D_3A_{45}S_1$
2	$D_6A_{45}S_1$
3	$D_9A_{45}S_1$
4	$D_{12}A_{45}S_1$
5	$D_3A_{90}S_1$
6	$D_6A_{90}S_1$
7	$D_9A_{90}S_1$
8	$D_{12}A_{90}S_1$
9	$D_3A_{45}S_2$
10	$D_6A_{45}S_2$
11	$D_9A_{45}S_2$
12	$D_{12}A_{45}S_2$
13	$D_3A_{90}S_2$
14	$D_6A_{90}S_2$
15	$D_9A_{90}S_2$
16	$D_{12}A_{90}S_2$

Table D1: Experimental Conditions - Study #3

Experimental design model: randomized mixed-nested factorial design

Main Effects	Symbol	Level	Type
Distance traveled	D_j	4	Fixed
Starting separation distance	S_k	2	Fixed
Angle of reach	A_l	2	Fixed
Handedness of subjects	H_m	2	Fixed
Subject	$O_{p(m)}$	7	Random
Residual	$E_{n(jklmp)}$	20	Random

Table D2: EMS Table - Study #3

$$EMS = a\sigma_e^2 + b\sigma_x^2 + c\phi_y$$

Source	D	S	A	H	O	R_n	a	b	x	c	y
D_j	0	2	2	2	7	20	1	80	DO	1120	D
S_k	4	0	2	2	7	20	1	160	SD	2240	S
A_l	4	2	0	2	7	20	1	160	AO	2240	A
H_m	4	2	2	0	7	20	1	320	0	2240	H
$O_{p(m)}$	4	2	2	1	1	20	1	320	0		
$(D*S)_{jk}$	0	0	2	2	7	20	1	40	DSO	560	DS
$(D*A)_{jl}$	0	2	0	2	7	20	1	40	DAO	560	DA
$(D*H)_{jm}$	0	2	2	0	7	20	1	80	DO	560	DH
$(D*O)_{jp(m)}$	0	2	2	1	1	20	1	80	DO		
$(S*A)_{kl}$	4	0	0	2	7	20	1	80	SAO	1120	SA
$(S*H)_{km}$	4	0	2	0	7	20	1	160	SO	1120	SH
$(S*O)_{kp(m)}$	4	0	2	1	1	20	1	160	SO		
$(A*H)_{lm}$	4	2	0	0	7	20	1	160	AO	1120	AH
$(A*O)_{lp(m)}$	4	2	0	1	1	20	1	160	AO		
$(D*S*A)_{jkl}$	0	0	0	2	7	20	1	20	DSAO	280	DSA
$(D*S*H)_{jkm}$	0	0	2	0	7	20	1	40	DSO	280	DSH
$(D*S*O)_{jkp(m)}$	0	0	2	1	1	20	1	40	DSO		

Table D2 : EMS Table - Study #3

$$EMS = a\sigma_e^2 + b\sigma_x^2 + c\phi_y$$

Source	D	S	A	H	O	R_n	a	b	x	c	y
$(D*A*H)_{jlm}$	0	2	0	0	7	20	1	40	DAO	280	DAH
$(D*A*O)_{jlp(m)}$	0	2	0	1	1	20	1	40	DAO		
$(S*A*H)_{klm}$	4	0	0	0	7	20	1	80	SAO	560	SAH
$(S*A*O)_{klp(m)}$	4	0	0	1	1	20	1	80	SAO		
$(D*S*A*H)_{jklm}$	0	0	0	0	7	20	1	20	DSAO	140	DSAH
$(D*S*A*O)_{jklp(m)}$	0	0	0	1	1	20	1	20	DSAO		
$E_{n(jklmp)}$	1	1	1	1	1	1	1				

Table D3 continued

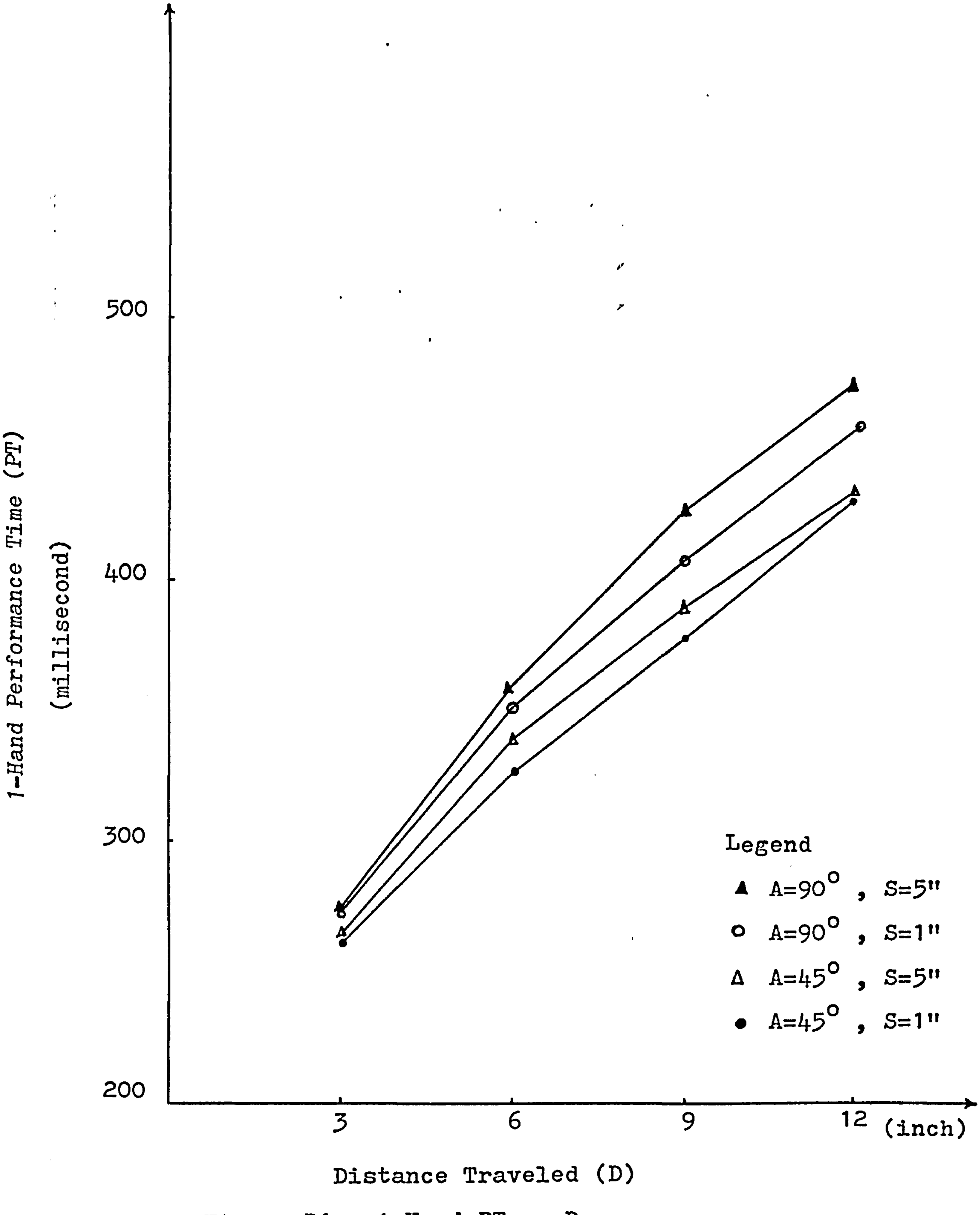

Figure D1. 1-Hand PT vs D

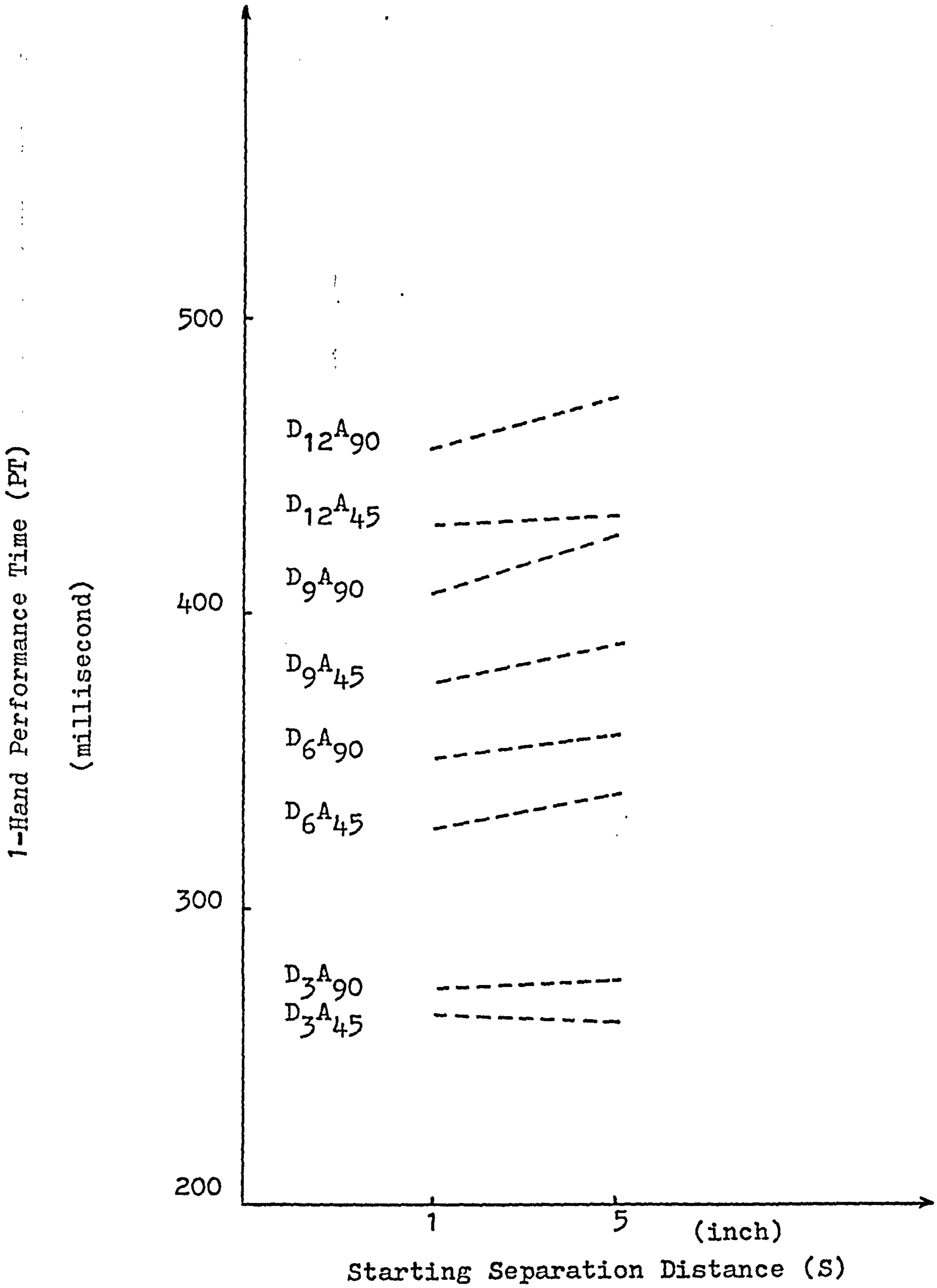

Figure D2. 1-Hand PT vs S

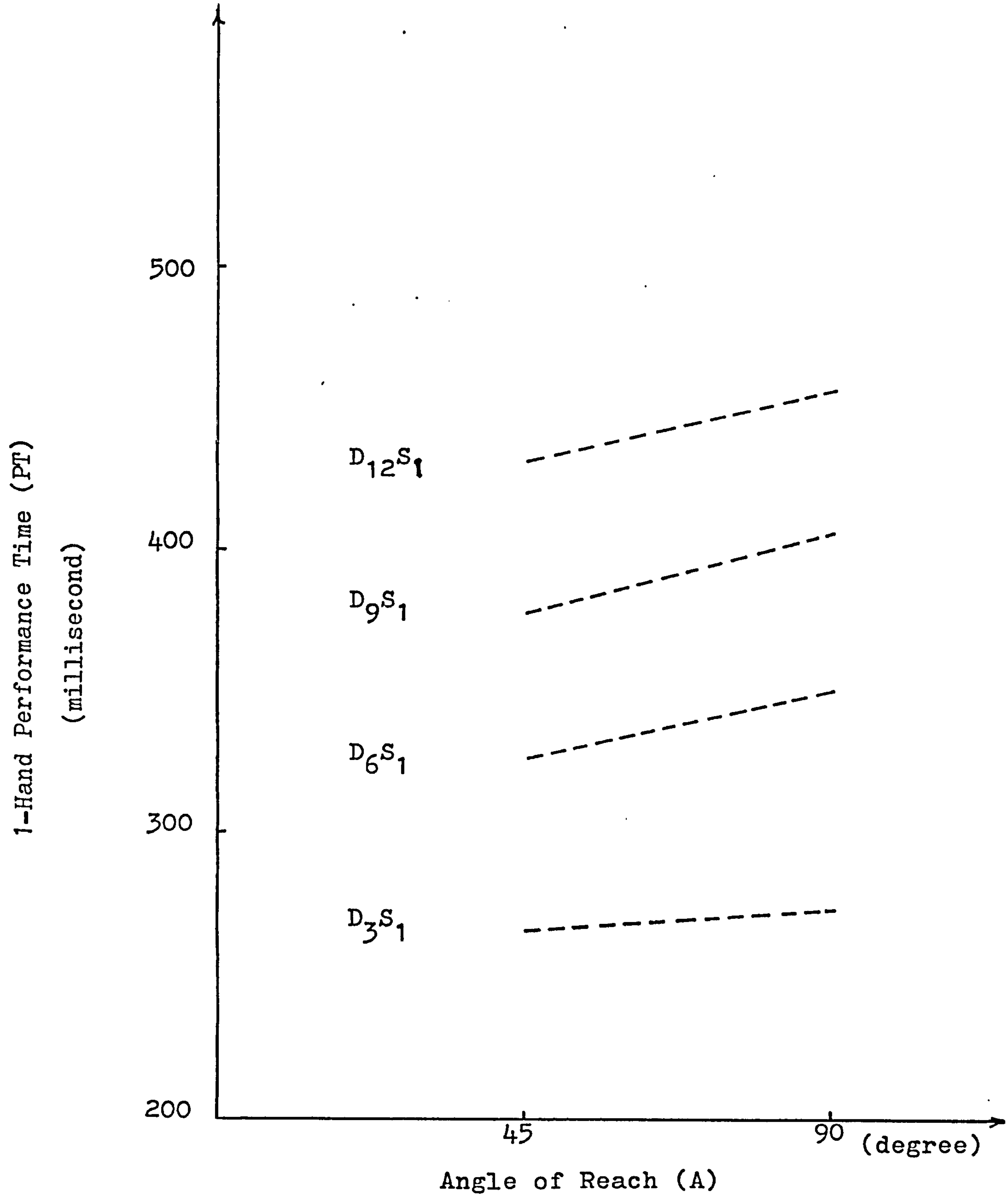

Figure D3. 1-Hand PT vs A

APPENDIX D.1

ANOVA - STUDY #3

STATISTICAL ANALYSIS SYSTEM   21:45 FRIDAY, JUNE 9, 1978   8

ANALYSIS OF VARIANCE PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
SUBJNO	7	1 2 3 4 5 6 7
D	4	1 2 3 4
A	2	1 2
S	2	1 2
HAND	2	1 2

NUMBER OF OBSERVATIONS IN DATA SET = 4480

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: PT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	223	31816996.63191652	142677.11494133	265.69	0.0001	0.932982	6.3471
ERROR	4256	2285493.75000316	537.00511043		STD DEV		PT MEAN
CORRECTED TOTAL	4479	34102490.38191968			23.17337072		365.10200893

SOURCE	DF	ANOVA SS	F VALUE	PR > F
HAND	1	13716.50022316	25.54	0.0001
SUBJNO(HAND)	12	7905377.40982139	1227.02	0.0001
D	3	20226286.45245534	12554.99	0.0001
D*HAND	3	53520.30602670	33.22	0.0001
SUBJNO*D(HAND)	36	443075.22530221	22.92	0.0001
A	1	717229.73772317	1335.61	0.0001
A*HAND	1	69622.97343755	129.65	0.0001
SUBJNO*A(HAND)	12	255528.34106339	39.67	0.0001
D*A	3	92771.66852677	57.59	0.0001
D*A*HAND	3	41204.23995525	25.58	0.0001
SUBJNO*D*A(HAND)	36	489756.35099260	25.33	0.0001
S	1	91993.43772316	171.31	0.0001
S*HAND	1	4153.93058038	7.75	0.0054
SUBJNO*S(HAND)	12	218430.69732124	33.90	0.0001
D*S	3	45531.95066959	28.88	0.0001
D*S*HAND	3	78249.34352678	48.57	0.0001
SUBJNO*D*S(HAND)	36	507144.30267799	26.23	0.0001
A*S	1	9785.13772322	18.22	0.0001
A*S*HAND	1	926.19843751	1.72	0.1892
SUBJNO*A*S(HAND)	12	121575.70446402	18.87	0.0001
D*A*S	3	15582.87924099	9.67	0.0001
D*A*S*HAND	3	19385.28281242	12.03	0.0001
SUBJNO*D*A*S(HAND)	36	393394.90982121	20.35	0.0001

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*D(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
D	3	20226286.45245534	547.80	0.0001

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
A	1	717229.73772317	33.67	0.0001

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
S	1	91993.43772316	5.05	0.0442

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*D*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
D*A	3	92771.66852677	2.27	0.0966

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: PT

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*D*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
D*S	3	46531.95066959	1.10	0.3613

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
A*S	1	9785.13772322	0.97	0.3451

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*D*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
D*A*S	3	15582.87924099	0.48	0.7014

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
S*HAND	1	4159.93058038	0.23	0.6412

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
A*HAND	1	69622.97343755	3.27	0.0957

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*D(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
D*HAND	3	53520.30602670	1.45	0.2446

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*D*A(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
D*A*HAND	3	41204.23995525	1.01	0.3998

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
A*S*HAND	1	926.19843751	0.09	0.7676

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*D*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
D*S*HAND	3	78246.34352678	1.85	0.1553

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: PT

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO*D*A*S(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
D*A*S*HAND	3	19385.28281242	0.59	0.6247

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUBJNO(HAND) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
HAND	1	13716.50022316	0.02	0.8977

APPENDIX D.2

COMPUTATION OF COMPONENT VARIANCES OF MAIN EFFECTS STUDY #3

From the results of ANOVA (Appendix D.1) and the EMS table (Table D2), we compute the component variances as follow:

$\sigma_e^2 + 80\,\sigma_e^2 = 12307.661$ $\qquad$ $\sigma_e^2 = 537.005$

$\sigma_e^2 + 1120\,\phi_D + 80\,\sigma_{DO}^2 = 6742095.3$ $\qquad$ $\phi_D = 6008.74$

$\sigma_e^2 + 2240\,\phi_S + 160\,\sigma_{SO}^2 = 91993.44$

$\sigma_e^2 + 160\,\sigma_{SO}^2 = 18206.725$ $\qquad$ $\phi_S = 32.94$

$\sigma_e^2 + 2240\,\phi_A + 160\,\sigma_{AO}^2 = 717229.74$

$\sigma_e^2 + 160\,\sigma_{AO}^2 = 21302.361$ $\qquad$ $\phi_A = 310.68$

$\sigma_0^2 = 2057.4305$

Total variance $= \sigma_0^2 + \phi_D + \phi_S + \phi_A$

$= 8409.79$

Therefore

Subject variance = 24.46 %

D = 71.45 %

A = 3.70 %

S = 0.39 %

APPENDIX D.3

DUNCAN'S MEANS TESTS OF MAIN EFFECTS

D, A, S

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   22:08 SATURDAY, JULY 22, 1[illegible]

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=4474   MS=2920.65

GROUPING	MEAN	N	D
A	448.465179	1120	4
B	403.063393	1120	3
C	343.933929	1120	2
D	267.945536	1120	1

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   22:08 SATURDAY, JULY 22, 1

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=4474   MS=2920.65

GROUPING	MEAN	N	A
A	377.754911	2240	2
B	352.449107	2240	1

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   22:08 SATURDAY, JULY 22, 1

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=4474   MS=2920.65

GROUPING	MEAN	N	S
A	369.633482	2240	2
B	360.570536	2240	1

APPENDIX D.4

DUNCAN'S MEANS TESTS OF OVERALL MEANS - STUDY #3

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   22:08 SATURDAY, JULY 22, 1978   3

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE PT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=4464   MS=2890.3

GROUPING	MEAN	N	CONDNO
A	473.721429	280	80
B	456.396429	280	72
C	432.932143	280	76
C	430.810714	280	68
C	427.478571	280	79
D	406.639286	280	71
E	388.575000	280	75
F	377.500714	280	67
G	359.914286	280	78
H	350.292857	280	70
I	339.975000	280	74
J	325.553571	280	66
K	273.942857	280	77
K	273.633571	280	69
L	263.657143	280	65
L	260.523571	280	73

APPENDIX D.5

MULTIPLE REGRESSION ANALYSIS WITH VARIABLES

D, A, S

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: MEANPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	520354.56032476	173451.52010825	160.24	0.0001	0.816556	9.0112
ERROR	108	116900.89609825	1082.41570461			STD DEV	MEANPT MEAN
CORRECTED TOTAL	111	637255.45642301				32.90008670	365.10200893

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
2	1	500123.98093860	462.04	0.0001	1	500123.98093860	462.04	0.0001
4	1	17930.74344308	16.57	0.0001	1	17930.74344308	16.57	0.0001
5	1	2299.83594308	2.12	0.1478	1	2299.83594308	2.12	0.1478

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	164.12678571	10.78	0.0001	15.22978077
2	59.76383929	21.50	0.0001	2.78056683
4	25.30580357	4.07	0.0001	6.21753197
5	9.06294643	1.46	0.1478	6.21753197

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL FOR MEAN	UPPER 95% CL FOR MEAN
1	298.80000000	258.26437500	40.53562500	244.76377562	271.76497438
2	324.90000000	318.03321429	6.86678571	307.01002105	329.05640752
3	394.12500000	377.80205357	16.32294643	366.77886033	388.82524681
4	444.30000000	437.57089286	6.72910714	424.07029347	451.07149224
5	304.05000000	283.57017857	20.47982143	270.06957919	297.07077796
6	379.80000000	343.33901786	36.46098214	332.31582462	354.36221109
7	450.60000000	403.10785714	47.49214286	392.08466391	414.13105038
8	481.42500000	462.87669643	18.54830357	449.37609704	476.37729581
9	273.30000000	267.32732143	5.97267857	253.82672204	280.82792081
10	368.17500000	327.09616071	41.07883929	316.07296748	338.11935395
11	445.50000000	386.86500000	58.63500000	375.84180676	397.88819324
12	506.70000000	446.63383929	60.06616071	433.13323990	460.13443867
13	294.60000000	292.63312500	1.96687500	279.13252562	306.13372438
14	406.72500000	352.40196429	54.32303571	341.37877105	363.42515752
15	454.95000000	412.17080357	42.77919643	401.14761033	423.19399681
16	511.27500000	471.93964286	39.33535714	458.43904347	485.44024224
17	234.30000000	258.26437500	-23.96437500	244.76377562	271.76497438
18	301.95000000	318.03321429	-16.08321429	307.01002105	329.05640752
19	377.17500000	377.80205357	-0.62705357	366.77886033	388.82524681
20	417.82500000	437.57089286	-19.74589286	424.07029347	451.07149224
21	274.57500000	283.57017857	-8.99517857	270.06957919	297.07077796
22	320.17500000	343.33901786	-23.16401786	332.31582462	354.36221109
23	399.22500000	403.10785714	-3.88285714	392.08466391	414.13105038
24	477.00000000	462.87669643	14.12330357	449.37609704	476.37729581
25	255.30000000	267.32732143	-12.02732143	253.82672204	280.82792081
26	351.45000000	327.09616071	24.35383929	316.07296748	338.11935395
27	379.05000000	386.86500000	-7.81500000	375.84180676	397.88819324
28	416.92500000	446.63383929	-29.70883929	433.13323990	460.13443867
29	275.25000000	292.63312500	-17.38312500	279.13252562	306.13372438
30	355.87500000	352.40196429	3.47303571	341.37877105	363.42515752
31	428.10000000	412.17080357	15.92919643	401.14761033	423.19399681
32	478.50000000	471.93964286	6.56035714	458.43904347	485.44024224
33	234.60000000	258.26437500	-23.66437500	244.76377562	271.76497438
34	313.87500000	318.03321429	-4.15821429	307.01002105	329.05640752
35	380.85000000	377.80205357	3.04794643	366.77886033	388.82524681
36	427.95000000	437.57089286	-9.62089286	424.07029347	451.07149224
37	247.50000000	283.57017857	-36.07017857	270.06957919	297.07077796
38	343.20000000	343.33901786	-0.13901786	332.31582462	354.36221109
39	378.97500000	403.10785714	-24.13285714	392.08466391	414.13105038
40	469.87500000	462.87669643	6.99830357	449.37609704	476.37729581
41	242.02500000	267.32732143	-25.30232143	253.82672204	280.82792081
42	330.97500000	327.09616071	3.87883929	316.07296748	338.11935395
43	381.30000000	386.86500000	-5.56500000	375.84180676	397.88819324
44	423.67500000	446.63383929	-22.95883929	433.13323990	460.13443867

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GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: MEANRT

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL FOR MEAN	UPPER 95% CL FOR MEAN
45	273.45000000	292.63312500	-19.18312500	279.13252562	306.13372438
46	339.90000000	352.40196429	-12.50196429	341.37877105	363.42515752
47	429.15000000	412.17080357	16.97919643	401.14761033	423.19399681
48	480.82500000	471.93964286	8.88535714	458.43904347	485.44024224
49	278.92500000	258.26437500	20.66062500	244.76377562	271.76497438
50	360.07500000	318.03321429	42.04178571	307.01002105	329.05640752
51	410.70000000	377.80205357	32.89794643	366.77886033	388.82524681
52	478.42500000	437.57089286	40.85410714	424.07029347	451.07149224
53	285.37500000	283.57017857	1.80482143	270.06957919	297.07077796
54	390.97500000	343.33901786	47.63598214	332.31582462	354.35221109
55	436.27500000	403.10785714	33.16714286	392.08466391	414.13105038
56	495.32500000	462.87669643	32.44830357	449.37609704	476.37729581
57	302.25000000	267.32732143	34.92267857	253.82672204	280.82792081
58	378.52500000	327.09616071	51.42883929	316.07296743	338.11935395
59	414.30000000	386.86500000	27.43500000	375.84180676	397.88819324
60	460.05000000	446.63383929	13.41616071	433.13323990	460.13443867
61	314.77500000	292.63312500	22.14187500	279.13252562	306.13372438
62	399.97500000	352.40196429	47.57303571	341.37877105	363.42515752
63	472.42500000	412.17080357	60.25419643	401.14761033	423.19399681
64	496.27500000	471.93964286	24.33535714	458.43904347	485.44024224
65	296.62500000	258.26437500	38.36062500	244.76377562	271.76497438
66	340.50000000	318.03321429	22.46678571	307.01002105	329.05640752
67	368.17500000	377.80205357	-9.62705357	366.77886033	388.82524681
68	452.62500000	437.57089286	15.05410714	424.07029347	451.07149224
69	280.50000000	283.57017857	-3.07017857	270.06957919	297.07077796
70	367.27500000	343.33901786	23.93598214	332.31582462	354.35221109
71	425.47500000	403.10785714	22.36714286	392.08466391	414.13105038
72	437.55000000	462.87669643	-25.32669643	449.37609704	476.37729581
73	252.45000000	267.32732143	-14.87732143	253.82672204	280.82792081
74	327.00000000	327.09616071	-0.09616071	316.07296748	338.11935395
75	368.55000000	386.86500000	-18.31500000	375.84180676	397.88819324
76	432.90000000	446.63383929	-13.73383929	433.13323990	460.13443867
77	263.02500000	292.63312500	-29.60812500	279.13252562	306.13372438
78	362.77500000	352.40196429	10.37303571	341.37877105	363.42515752
79	409.35000000	412.17080357	-2.82080357	401.14761033	423.19399681
80	486.00000000	471.93964286	14.06035714	458.43904347	485.44024224
81	221.10000000	258.26437500	-37.16437500	244.76377562	271.76497438
82	283.95000000	318.03321429	-34.08321429	307.01002105	329.05640752
83	306.30000000	377.80205357	-71.50205357	366.77886033	388.82524681
84	355.42500000	437.57089286	-82.14589286	424.07029347	451.07149224
85	238.57500000	283.57017857	-44.99517857	270.06957919	297.07077796
86	307.12500000	343.33901786	-36.21401786	332.31582462	354.35221109
87	350.02500000	403.10785714	-53.08285714	392.08466391	414.13105038
88	390.85000000	462.87669643	-72.02669643	449.37609704	476.37729581
89	231.75000000	267.32732143	-35.57732143	253.82672204	280.82792081
90	284.25000000	327.09616071	-42.84616071	316.07296748	338.11935395
91	333.52500000	386.86500000	-53.34000000	375.84180676	397.88819324
92	354.60000000	446.63383929	-92.03383929	433.13323990	460.13443867
93	237.82500000	292.63312500	-54.80812500	279.13252562	306.13372438
94	302.40000000	352.40196429	-50.00196429	341.37877105	363.42515752
95	365.10000000	412.17080357	-47.07080357	401.14761033	423.19399681
96	400.57500000	471.93964286	-71.36464286	458.43904347	485.44024224
97	281.25000000	258.26437500	22.98562500	244.76377562	271.76497438
98	353.62500000	318.03321429	35.59178571	307.01002105	329.05640752
99	405.60000000	377.80205357	27.79794643	366.77886033	388.82524681
100	439.12500000	437.57089286	1.55410714	424.07029347	451.07149224
101	285.00000000	283.57017857	1.42982143	270.06957919	297.07077796
102	343.50000000	343.33901786	0.16098214	332.31582462	354.35221109
103	405.90000000	403.10785714	2.79214286	392.08466391	414.13105038
104	452.25000000	462.87669643	-10.62669643	449.37609704	476.37729581
105	266.62500000	267.32732143	-0.70232143	253.82672204	280.82792081
106	334.35000000	327.09616071	7.25383929	316.07296748	338.11935395
107	397.80000000	386.86500000	10.93500000	375.84180676	397.88819324
108	435.67500000	446.63383929	-10.95883929	433.13323990	460.13443867
109	258.67500000	292.63312500	-33.95812500	279.13252562	306.13372438
110	351.75000000	352.40196429	-0.65196429	341.37877105	363.42515752
111	433.27500000	412.17080357	21.10419643	401.14761033	423.19399681
112	462.60000000	471.93964286	-9.33964286	458.43904347	485.44024224

MULTIPLE REGRESSION FOR SINGLE HAND   15:57 MONDAY, JULY 3, 1978   13

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: MEANPT

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	116900.89609821
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000003
FIRST ORDER AUTOCORRELATION	0.69000612
DURBIN-WATSON D	0.61543002

APPENDIX D.6

MULTIPLE REGRESSION ANALYSIS WITH VARIABLES

D, A

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: MEANPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	2	518054.72438168	259027.36219084	236.86	0.0001	0.812947	9.0576
ERROR	109	119200.73204133	1093.58469763		STD DEV		MEANPT MEAN
CORRECTED TOTAL	111	637255.45642301			33.06939216		365.10200893

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
D	1	500123.98093860	457.33	0.0001	1	500123.98093860	457.33	0.0001
A	1	17930.74344308	16.40	0.0001	1	17930.74344308	16.40	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	177.72120536	14.69	0.0001	12.10215333
D	59.76883929	21.39	0.0001	2.79467375
A	25.30580357	4.05	0.0001	6.24952769

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL FOR MEAN	UPPER 95% CL FOR MEAN
1	298.80000000	262.79584821	36.00415179	250.72303998	274.86865645
2	324.90000000	322.56468750	2.33531250	313.37865781	331.75071719
3	394.12500000	382.33352679	11.79147321	373.14749710	391.51955647
4	444.30000000	442.10236607	2.19763393	430.02955783	454.17517431
5	304.05000000	288.10165179	15.94834821	276.02884355	300.17446002
6	379.80000000	347.87049107	31.92950893	338.68446139	357.05652076
7	450.60000000	407.63933036	42.96066964	398.45330067	416.82536004
8	481.42500000	467.40816964	14.01683036	455.33536140	479.48097788
9	273.30000000	262.79584821	10.50415179	250.72303998	274.86865645
10	368.17500000	322.56468750	45.61031250	313.37865781	331.75071719
11	445.50000000	382.33352679	63.16647321	373.14749710	391.51955647
12	506.70000000	442.10236607	64.59763393	430.02955783	454.17517431
13	294.60000000	288.10165179	6.49834821	276.02884355	300.17446002
14	406.72500000	347.87049107	58.85450893	338.68446139	357.05652076
15	454.95000000	407.63933036	47.31066964	398.45330067	416.82536004
16	511.27500000	467.40816964	43.86683036	455.33536140	479.48097788
17	234.30000000	262.79584821	-28.49584821	250.72303998	274.86865645
18	301.95000000	322.56468750	-20.61468750	313.37865781	331.75071719
19	377.17500000	382.33352679	-5.15852679	373.14749710	391.51955647
20	417.82500000	442.10236607	-24.27736607	430.02955783	454.17517431
21	274.57500000	288.10165179	-13.52665179	276.02884355	300.17446002
22	320.17500000	347.87049107	-27.69549107	338.68446139	357.05652076
23	399.22500000	407.63933036	-8.41433036	398.45330067	416.82536004
24	477.00000000	467.40816964	9.59183036	455.33536140	479.48097788
25	255.30000000	262.79584821	-7.49584821	250.72303998	274.86865645
26	351.45000000	322.56468750	28.88531250	313.37865781	331.75071719
27	379.05000000	382.33352679	-3.28352679	373.14749710	391.51955647
28	416.92500000	442.10236607	-25.17736607	430.02955783	454.17517431
29	275.25000000	288.10165179	-12.85165179	276.02884355	300.17446002
30	355.87500000	347.87049107	8.00450893	338.68446139	357.05652076
31	428.10000000	407.63933036	20.46066964	398.45330067	416.82536004
32	478.50000000	467.40816964	11.09183036	455.33536140	479.48097788
33	234.60000000	262.79584821	-28.19584821	250.72303998	274.86865645
34	313.87500000	322.56468750	-8.68968750	313.37865781	331.75071719
35	380.85000000	382.33352679	-1.48352679	373.14749710	391.51955647
36	427.95000000	442.10236607	-14.15236607	430.02955783	454.17517431
37	247.50000000	288.10165179	-40.60165179	276.02884355	300.17446002
38	343.20000000	347.87049107	-4.67049107	338.68446139	357.05652076
39	378.97500000	407.63933036	-28.66433036	398.45330067	416.82536004
40	469.87500000	467.40816964	2.46683036	455.33536140	479.48097788
41	242.02500000	262.79584821	-20.77084821	250.72303998	274.86865645
42	336.07500000	322.56468750	13.51031250	313.37865781	331.75071719
43	381.30000000	382.33352679	-1.03352679	373.14749710	391.51955647
44	423.67500000	442.10236607	-18.42736607	430.02955783	454.17517431
45	273.45000000	288.10165179	-14.65165179	276.02884355	300.17446002
46	339.90000000	347.87049107	-7.97049107	338.68446139	357.05652076

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: MEANPT

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL FOR MEAN	UPPER 95% CL FOR MEAN
47	429.15000000	407.63933036	21.51066964	398.45330067	416.82536004
48	480.82500000	467.40816964	13.41683036	455.33536140	479.48097788
49	278.92500000	262.79584821	16.12915179	250.72303998	274.86865645
50	360.07500000	322.56468750	37.51031250	313.37865781	331.75071719
51	410.70000000	382.33352679	28.36647321	373.14749710	391.51955647
52	478.42500000	442.10236607	36.32263393	430.02955783	454.17517431
53	285.37500000	288.10165179	-2.72665179	276.02884355	300.17446002
54	390.97500000	347.87049107	43.10450893	338.68446139	357.05652076
55	436.27500000	407.63933036	28.63566964	398.45330067	416.82536004
56	495.82500000	467.40816964	28.41683036	455.33536140	479.48097788
57	302.25000000	262.79584821	39.45415179	250.72303998	274.86865645
58	378.52500000	322.56468750	55.96031250	313.37865781	331.75071719
59	414.30000000	382.33352679	31.96647321	373.14749710	391.51955647
60	460.05000000	442.10236607	17.94763393	430.02955783	454.17517431
61	314.77500000	288.10165179	26.67334821	276.02884355	300.17446002
62	399.97500000	347.87049107	52.10450893	338.68446139	357.05652076
63	472.42500000	407.63933036	64.78566964	398.45330067	416.82536004
64	496.27500000	467.40816964	28.86683036	455.33536140	479.48097788
65	296.62500000	262.79584821	33.82915179	250.72303998	274.86865645
66	340.50000000	322.56468750	17.93531250	313.37865781	331.75071719
67	368.17500000	382.33352679	-14.15852679	373.14749710	391.51955647
68	452.62500000	442.10236607	10.52263393	430.02955783	454.17517431
69	280.50000000	288.10165179	-7.60165179	276.02884355	300.17446002
70	367.27500000	347.87049107	19.40450893	338.68446139	357.05652076
71	425.47500000	407.63933036	17.83566964	398.45330067	416.82536004
72	437.55000000	467.40816964	-29.85816964	455.33536140	479.48097788
73	252.45000000	262.79584821	-10.34584821	250.72303998	274.86865645
74	327.00000000	322.56468750	4.43531250	313.37865781	331.75071719
75	368.55000000	382.33352679	-13.78352679	373.14749710	391.51955647
76	432.90000000	442.10236607	-9.20236607	430.02955783	454.17517431
77	263.02500000	288.10165179	-25.07665179	276.02884355	300.17446002
78	362.77500000	347.87049107	14.90450893	338.68446139	357.05652076
79	409.35000000	407.63933036	1.71066964	398.45330067	416.82536004
80	486.00000000	467.40816964	18.59183036	455.33536140	479.48097788
81	221.10000000	262.79584821	-41.69584821	250.72303998	274.86865645
82	283.95000000	322.56468750	-38.61468750	313.37865781	331.75071719
83	306.30000000	382.33352679	-76.03352679	373.14749710	391.51955647
84	355.42500000	442.10236607	-86.67736607	430.02955783	454.17517431
85	238.57500000	288.10165179	-49.52665179	276.02884355	300.17446002
86	307.12500000	347.87049107	-40.74549107	338.68446139	357.05652076
87	350.02500000	407.63933036	-57.61433036	398.45330067	416.82536004
88	380.85000000	467.40816964	-86.55816964	455.33536140	479.48097788
89	231.75000000	262.79584821	-31.04584821	250.72303998	274.86865645
90	284.25000000	322.56468750	-38.31468750	313.37865781	331.75071719
91	333.52500000	382.33352679	-48.80852679	373.14749710	391.51955647
92	354.60000000	442.10236607	-87.50236607	430.02955783	454.17517431
93	237.82500000	288.10165179	-50.27665179	276.02884355	300.17446002
94	302.40000000	347.87049107	-45.47049107	338.68446139	357.05652076
95	365.10000000	407.63933036	-42.53933036	398.45330067	416.82536004
96	400.57500000	467.40816964	-66.83316964	455.33536140	479.48097788
97	281.25000000	262.79584821	18.45415179	250.72303998	274.86865645
98	353.62500000	322.56468750	31.06031250	313.37865781	331.75071719
99	405.60000000	382.33352679	23.26647321	373.14749710	391.51955647
100	439.12500000	442.10236607	-2.97736607	430.02955783	454.17517431
101	285.00000000	288.10165179	-3.10165179	276.02884355	300.17446002
102	343.50000000	347.87049107	-4.37049107	338.68446139	357.05652076
103	405.90000000	407.63933036	-1.73933036	398.45330067	416.82536004
104	452.25000000	467.40816964	-15.15816964	455.33536140	479.48097788
105	266.62500000	262.79584821	3.82915179	250.72303998	274.86865645
106	334.35000000	322.56468750	11.78531250	313.37865781	331.75071719
107	397.80000000	382.33352679	15.46647321	373.14749710	391.51955647
108	435.67500000	442.10236607	-6.42736607	430.02955783	454.17517431
109	258.67500000	288.10165179	-29.42665179	276.02884355	300.17446002
110	351.75000000	347.87049107	3.87950893	338.68446139	357.05652076
111	433.27500000	407.63933036	25.63566964	398.45330067	416.82536004
112	462.60000000	467.40816964	-4.80816964	455.33536140	479.48097788

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GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: MEANPT

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	119200.73204129
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000003
FIRST ORDER AUTOCORRELATION	0.69033842
DURBIN-WATSON D	0.61591535

APPENDIX E.0

SIMULTANEITY: A MEASURE OF TIME DIFFERENCE BETWEEN PR AND PL

Simultaneity: A Measure of Time Difference between PR and PL

CONDITION NO. 1	MEAN	336.6857	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	14.0464	4.172	%	NO. OF CYCLES	280
CONDITION NO. 2	MEAN	420.9107	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	32.9679	7.833	%	NO. OF CYCLES	280
CONDITION NO. 3	MEAN	487.5214	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	39.3857	8.079	%	NO. OF CYCLES	280
CONDITION NO. 4	MEAN	532.4679	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	37.2214	6.990	%	NO. OF CYCLES	280
CONDITION NO. 5	MEAN	442.4679	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	25.3821	5.736	%	NO. OF CYCLES	280
CONDITION NO. 6	MEAN	475.3179	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	22.7357	4.783	%	NO. OF CYCLES	280
CONDITION NO. 7	MEAN	509.9786	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	28.4464	5.578	%	NO. OF CYCLES	280
CONDITION NO. 8	MEAN	571.3500	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	35.0893	6.141	%	NO. OF CYCLES	280
CONDITION NO. 9	MEAN	465.5357	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	33.1071	7.112	%	NO. OF CYCLES	280
CONDITION NO. 10	MEAN	533.9571	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	28.1679	5.275	%	NO. OF CYCLES	280
CONDITION NO. 11	MEAN	566.0143	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	25.1571	4.445	%	NO. OF CYCLES	280
CONDITION NO. 12	MEAN	606.3857	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	30.8571	5.089	%	NO. OF CYCLES	280
CONDITION NO. 13	MEAN	518.8286	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	37.5214	7.232	%	NO. OF CYCLES	280
CONDITION NO. 14	MEAN	545.6250	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	33.5893	6.156	%	NO. OF CYCLES	280
CONDITION NO. 15	MEAN	603.2357	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	38.0250	6.304	%	NO. OF CYCLES	280
CONDITION NO. 16	MEAN	652.3714	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	33.4500	5.127	%	NO. OF CYCLES	280
CONDITION NO. 17	MEAN	326.4857	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	13.2964	4.073	%	NO. OF CYCLES	280
CONDITION NO. 18	MEAN	420.5464	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	33.4071	7.944	%	NO. OF CYCLES	280
CONDITION NO. 19	MEAN	492.7071	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	49.2000	9.986	%	NO. OF CYCLES	280
CONDITION NO. 20	MEAN	551.1857	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	54.8143	9.945	%	NO. OF CYCLES	280
CONDITION NO. 21	MEAN	419.9250	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	22.1357	5.271	%	NO. OF CYCLES	280
CONDITION NO. 22	MEAN	413.5714	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	16.4679	3.982	%	NO. OF CYCLES	280
CONDITION NO. 23	MEAN	466.7893	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	30.4393	6.521	%	NO. OF CYCLES	280
CONDITION NO. 24	MEAN	565.7679	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	40.2643	7.117	%	NO. OF CYCLES	280
CONDITION NO. 25	MEAN	494.5393	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	29.1964	5.904	%	NO. OF CYCLES	280
CONDITION NO. 26	MEAN	491.5607	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	20.1643	4.102	%	NO. OF CYCLES	280
CONDITION NO. 27	MEAN	484.1786	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	16.1143	3.328	%	NO. OF CYCLES	280
CONDITION NO. 28	MEAN	547.2750	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	28.0071	5.118	%	NO. OF CYCLES	280
CONDITION NO. 29	MEAN	520.5107	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	46.7250	8.977	%	NO. OF CYCLES	280
CONDITION NO. 30	MEAN	540.5036	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	30.6750	5.675	%	NO. OF CYCLES	280
CONDITION NO. 31	MEAN	542.4536	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	20.5821	3.794	%	NO. OF CYCLES	280
CONDITION NO. 32	MEAN	559.2264	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	21.8893	3.914	%	NO. OF CYCLES	280
CONDITION NO. 33	MEAN	379.3500	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	20.3679	5.369	%	NO. OF CYCLES	280
CONDITION NO. 34	MEAN	474.5250	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	36.2357	7.636	%	NO. OF CYCLES	280
CONDITION NO. 35	MEAN	520.9714	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	40.9607	7.862	%	NO. OF CYCLES	280
CONDITION NO. 36	MEAN	567.4821	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	47.1750	8.313	%	NO. OF CYCLES	280
CONDITION NO. 37	MEAN	498.1071	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	26.2071	5.261	%	NO. OF CYCLES	280
CONDITION NO. 38	MEAN	535.6500	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	31.3607	5.855	%	NO. OF CYCLES	280
CONDITION NO. 39	MEAN	599.8179	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	29.7107	4.953	%	NO. OF CYCLES	280
CONDITION NO. 40	MEAN	602.8821	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	34.7571	5.765	%	NO. OF CYCLES	280
CONDITION NO. 41	MEAN	514.0607	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	33.9643	6.607	%	NO. OF CYCLES	280
CONDITION NO. 42	MEAN	582.9857	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	36.2786	6.223	%	NO. OF CYCLES	280
CONDITION NO. 43	MEAN	629.0036	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	35.8071	5.693	%	NO. OF CYCLES	280
CONDITION NO. 44	MEAN	673.4571	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	36.4500	5.412	%	NO. OF CYCLES	280
CONDITION NO. 45	MEAN	576.8036	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	38.7321	6.715	%	NO. OF CYCLES	280
CONDITION NO. 46	MEAN	620.4964	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	48.7607	7.858	%	NO. OF CYCLES	280
CONDITION NO. 47	MEAN	664.8214	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	42.3000	6.363	%	NO. OF CYCLES	280
CONDITION NO. 48	MEAN	711.5786	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	37.5429	5.276	%	NO. OF CYCLES	280
CONDITION NO. 49	MEAN	382.2107	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	16.4250	4.297	%	NO. OF CYCLES	280
CONDITION NO. 50	MEAN	466.8750	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	41.7643	8.945	%	NO. OF CYCLES	280
CONDITION NO. 51	MEAN	529.4143	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	46.7036	8.822	%	NO. OF CYCLES	280
CONDITION NO. 52	MEAN	578.6143	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	52.5750	9.086	%	NO. OF CYCLES	280
CONDITION NO. 53	MEAN	459.4714	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	28.2964	6.158	%	NO. OF CYCLES	280
CONDITION NO. 54	MEAN	473.0929	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	21.0750	4.447	%	NO. OF CYCLES	280
CONDITION NO. 55	MEAN	528.8679	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	34.8643	6.592	%	NO. OF CYCLES	280
CONDITION NO. 56	MEAN	591.2786	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	42.2786	7.150	%	NO. OF CYCLES	280
CONDITION NO. 57	MEAN	516.2464	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	39.7714	7.704	%	NO. OF CYCLES	280
CONDITION NO. 58	MEAN	552.0321	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	26.4000	4.782	%	NO. OF CYCLES	280
CONDITION NO. 59	MEAN	577.3179	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	24.2357	4.198	%	NO. OF CYCLES	280
CONDITION NO. 60	MEAN	602.7750	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	32.2714	5.354	%	NO. OF CYCLES	280
CONDITION NO. 61	MEAN	570.0536	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	44.6464	7.832	%	NO. OF CYCLES	280
CONDITION NO. 62	MEAN	586.6714	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	31.2321	5.324	%	NO. OF CYCLES	280
CONDITION NO. 63	MEAN	581.8714	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	27.4393	4.716	%	NO. OF CYCLES	280
CONDITION NO. 64	MEAN	610.7500	AVERAGE ABS(PR-PL) FOR ALL SUBJECTS	29.5607	4.777	%	NO. OF CYCLES	280

APPENDIX F.0

GLOSSARY OF SYMBOLS

A	Angle of reach
B	Distances traveled by 2 hands for symmetrical simultaneous motions
D	Distance traveled by the preferred hand for single-handed reach motions
H or HAND	Handedness of either right-handed or left-handed subjects
L	Distance traveled by the left hand
O or Subjno	Subject
R	Distance traveled by the right hand
S	Starting separation distance
$BM_{( )}$	Biomechanical effects due to D, A, S
BT	Balancing tendency effect
PL	Performance time for the left hand
PR	Performance time for the right hand
PT	Performance time
$PT_{SH( )}$	Mean performance time for single-handed reach motions with the condition's levels indicated by the number in the bracket
$PT_{BH( )}$	Mean performance time for asymmetrical simultaneous motions with the condition's levels indicated by the number in the bracket
VE	Visual search effect
DVS	Deterministic visual search strategy

PVS	Probabilistic visual search
SIMO	Simultaneous motions
SYMPT	Performance time for symmetrical SIMO
SYM-SIMO	Symmetrical simultaneous motions
ASYM-SIMO	Asymmetrical simultaneous motions
$^{B}(\ )^{A}(\ )^{S}(\ )$	Represents the condition performed by the subjects at different levels of B, A, S

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VITA AUCTORIS

1948 Born in Kwang-tung, China on December 31.

1969 Completed secondary education from North Park Collegiate, Brantford, Ontario.

1973 Graduated with Bachelor of Engineering from McMaster University, Department of Electrical Engineering, Hamilton, Ontario.

1976 Graduated with Bachelor of Commerce from University of Windsor, Faculty of Business Administration, Windsor, Ontario.

1978 Currently employ with General Motors of Canada Limited, Diesel Division, London, Ontario in Industrial Engineering functions.
Currently a candidate for the degree of Master of Applied Science in Industrial Engineering.